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CHEMICAL LAWS AND PROBLEMS.

JOHN PILLEY.

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BY

JOHN J. PILLEY, F.C.S.,

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PREFACE.

HAVING felt the want, for teaching purposes, of a series of *Chemical Problems* systematically arranged, I set myself the task of selecting and classifying for the use of my students, the questions in Chemical Arithmetic which have been set by several of the Public Examining Bodies. From the marked benefit which attended the use of these graduated examples, I have now found it desirable to add to them for the purpose of making the work more useful in a larger sphere. With this object in view I have prefixed to them sections on *the more important Chemical Definitions, Nomenclature, Notation, and Notes on the Chemical Laws and Theories.* Rules for working different varieties of Chemical Problems are also given.

The methods employed admit of variations and modifications, which will, doubtless, after the explanations given, suggest themselves alike to the teacher and the intelligent student. Most of the *Atomic Weights* employed in working the problems, are those printed in the Table on pages 114 and 115 as approximate; in exceptional cases, where great accuracy is necessary, the exact atomic weights given by the latest observers have been used.

The majority of the questions have been selected from the papers set at the following examinations:—*Oxford and Cambridge Local, London University, Science and Art Department, Owen's College,* and the *College of Preceptors,* and to the authors of such, I desire to acknowledge my indebtedness and to convey my thanks. The remaining problems have been designed by the author to

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illustrate certain rules and methods of working where suitable examples could not be obtained from examination papers.

In my own classes, for many reasons, I find it convenient to have the answers and solutions to problems in a separate book; and, for the benefit of those Students who cannot avail themselves of a teacher's aid, I have prepared a separate work containing fully solved problems.

In working and verifying the examples, I must acknowledge the most valuable assistance which I have received from my Students during the years 1884 to 1891, and I must offer my most hearty thanks to my colleague, Mr. W. N. EDWARDS, for the services he has rendered in revising the proof sheets.

J. J. P.

DULWICH, *Oct., 1891.*

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CHEMICAL LAWS
AND
ARITHMETICAL PROBLEMS.

I.—INTRODUCTION.

1.—THE METRIC SYSTEM.

1. **The Metric System** of weights and measures is generally employed in scientific experiments, this system was originally based upon the measurements of the earth's circumference, the *unit* of length called a *metre* was considered to be exactly the ten millionth part of the distance from the equator to either pole, although later researches have proved that the measurement was inexact, yet the unit metre, represented by a bar of platinum, preserved in Paris, is employed as a standard in all scientific work. The great convenience of this system is to be found in the fact that it is constructed upon the decimal plan, the units of length, capacity, and weight being multiplied or divided by 10, 100, or 1000. The system is in general use in France and Germany, although it is not employed for ordinary purposes in this country.

In comparison with English measures, the metre is equal to—

1·0396 yards.
3·2809 feet.
39·3707 inches.

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2. Prefixes.—The following Greek and Latin prefixes are employed to denote the multiples or decimal fractions of the unit. Thus, the prefixes of Greek origin—*myria*, *kilo*, *hecto*, *deka*, are used for multiples of 10,000, 1000, 100, 10 respectively; while the Latin prefixes—*decem*, *centum*, *mille*, are employed to express the decimal fractions, ·1, ·01, ·001. Thus, then the prefixes are—

Myria-	10,000	
Kilo-	1,000	
Hecto-	100	
Deca-	10	
The Unit	1	
Deci-	·1	or $\frac{1}{10}$
Centi-	·01	or $\frac{1}{100}$
Milli-	·001	or $\frac{1}{1000}$

For measures of **length** add the word **metre** after the hyphen.

" " **capacity** " " **litre** " "

" " **weight** " " **gram** " "

thus :—

Milli-metre. **Centi-litre.** **Kilo-gram.**

3. Measures of Length.—The unit is the **metre**, and the measures most commonly employed in scientific calculations are given below :—

1000 Millimetres (mm)	=	1 metre (m).
100 Centimetres (cm)	=	" "
10 Decimetres (dcm)	=	" "
1 Inch	=	2·54 cm.
1 Metre	=	39·371 inches.

4. The Use of the Decimal.—A length given in any one of these measures may be expressed in terms of another measure by simply moving the decimal point to the right or left.

Thus, 17,856,342 mm. may be written as kilometres by observing that millimetres are changed to metres by moving the point three places to the left; and these metres into kilometres by carrying it three places further, making, in all, six places.

Therefore, 17,856,342 mm. = 17,856·342 m. = 17·856342 km.

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Again, 4·876326 km. may be written as centimetres by observing that kilometres are changed to metres by moving the point three places to the right, and metres to centimetres by moving it to two places further, making, in all, five places.

Therefore, 4·876326 km. = 4,876·326 m. = 487,632·6 cm.

5. Measures of Volume.—If we take a cube, one edge of which is 10 centimetres, we obtain the unit of volume, which is one **cubic decimetre**, and which is known as one **litre.**

1 Cubic decimetres (c.dem.) = 1 litre.
1000 Cubic centimetres (cc.) = ,,
1 gallon = 4 quarts = 4·544 litres.
1 pint = 20 fluid ozs. = 567·9 cc.

6. Measures of Mass.—The unit mass employed is the **gramme (gram)**, and in scientific work we usually employ also the kilogram and milligram.

1 Kilogram = 1000 grams = 2·205 lbs. (avoird.)
1 Milligram = ·001 gram = 0·015 grain.

The volume of one gram of pure water at 4°C is **one cubic centimetre**; and the volume of a kilogram of water under like conditions is **one litre** (1000cc).

1 grain = ·0648 gram.
1 lb. avoirdupois = 453·6 grams.
1 oz. = 28·35 ,,

In the figure given on page 12 the relationship between a centimetre, a square centimetre, a cubic centimetre, a thousand cubic centimetres or litre, and English inches, is shown pictorially.

The complete tables of the metric system with the comparative English weights and measures are given in detail in the appendix, on pages 123 to 127.

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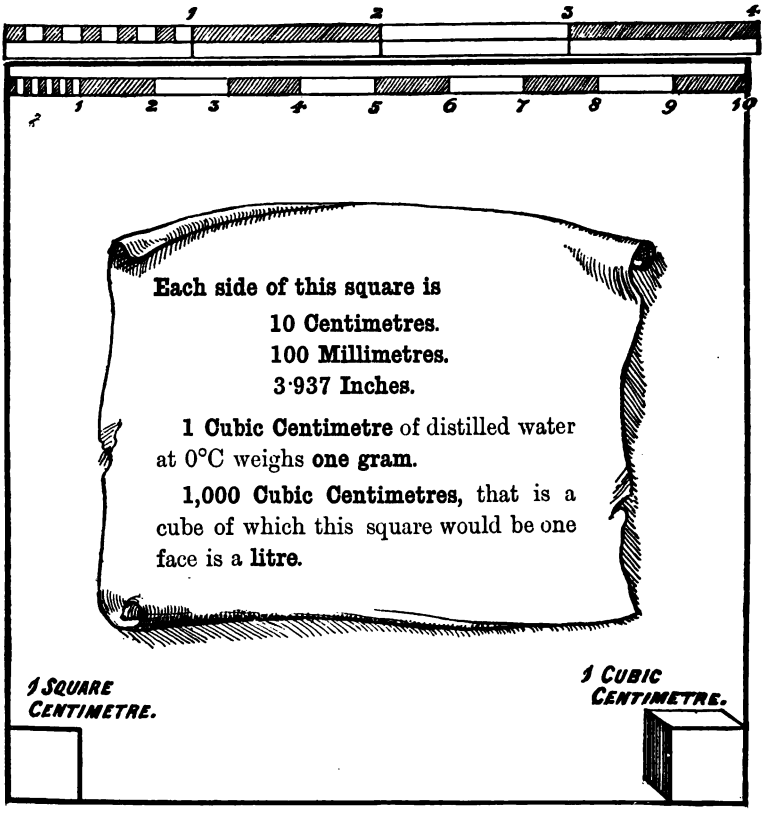
1
2
3
4
1 2 3 4 5 6 7 8 9 10
Each side of this square is
10 Centimetres.
100 Millimetres.
3·937 Inches.
1 Cubic Centimetre of distilled water at 0°C weighs one gram.
1,000 Cubic Centimetres, that is a cube of which this square would be one face is a litre.
1 Square Centimetre.
1 Cubic Centimetre.

7.—EXAMPLES ON THE METRIC SYSTEM.

1. Express each of the following as metres:—15 kilometres; 1 hectometre; 25 decimetres; 100 centimetres; 786 millimetres; 464 centimetres.

2. Express each of the following as litres:—36 kilolitres; 1,000 cubic centimetres; 1 cubic centimetre; 37,984,638 cubic millimetres.

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3. Express in cubic centimetres—1 litre; 27 litres; 1 hectolitre; 18 millilitres.

4. Reduce 10 kilometres, 321 metres to English measure.

$$\begin{aligned} \text{10 kilometres, 321 metres} &= 10321 \text{ metres} \\ &= (10321 \times 1{\cdot}094) \text{ yards} \\ &= \frac{10321 \times 1{\cdot}094}{1760} \text{ miles} \\ &= 6 \text{ miles } 731{\cdot}174 \text{ yards} \end{aligned}$$

5. Express 2 miles 309 yards in the metric system.

$$\begin{aligned} \text{2 miles 309 yards} &= \{(1760 \times 2) + 309\} \text{ yards} \\ &= 3829 \text{ yards} \\ &= \frac{3829}{1{\cdot}094} \text{ metres} \\ &= 3500 \text{ metres} \end{aligned}$$

6. In 1,235 litres, how many gallons?

7. How many grains avoirdupois are equal to 765 grams?

8. Reduce 765 litres 14 cubic centimetres to cubic centimetres.

9. Reduce 276 metres to English measure.

10. How many inches are equal to 897 millimetres?

11. Convert 765 millimetres into inches.

12. A gallon is equal to 4·543 litres. How many cubic centimetres are contained in a quart?

13. Express in centimetres, (*a*) 1 yard, (*b*) 4 feet, (*c*) 32 inches.

14. The velocity of light in air is 299,740,000 metres per second. Express this velocity in yards per second, and in miles per minute.

15. What do you consider the chief advantages of the metric system over that usually employed in this country?

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2.—IMPORTANT CHEMICAL DEFINITIONS.

1. **A Chemical Element** is a body which cannot be resolved into any simpler form, or a substance from which no other body can be extracted by any known physical means.

2. **A Chemical Compound** is a body which is composed of two or more elements *united* by the force of chemical affinity.

3. **A Mechanical Mixture** may be made up of two or more elements or compounds which are not united by the force of chemical affinity, and which ingredients retain their individual physical properties.

> The bodies which *unite* to form a chemical compound do not retain their physical properties, but usually the resulting compound possesses characteristics entirely different from those of the ingredients of which it is composed.

4. **An Atom** is the smallest portion of matter which can enter into chemical *combination* or be liberated from a chemical compound.

5. **A Molecule** is the smallest quantity of an element or compound which can exist in the free state.

6. **The Atomic Weight** of an element is the number which represents the weight of an atom as compared with that which stands for the weight of an atom of hydrogen.

> Since hydrogen is the lightest known substance, and since, also, with few exceptions, all atoms are the same size, the atoms of hydrogen must be lighter than those of any other known element. The hydrogen atom is therefore adopted as the unit of comparison of atomic weights.

7. **The Molecular Weight of a Compound** is the sum of the atomic weights of the component elements present in the molecule.

8. **The Molecular Weight of an Element** is usually taken as twice its atomic weight.

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9. The Equivalent of an Element is the proportion by weight in which any simple substance will combine with one part by weight of hydrogen.

10. The Valency, Atomicity or **Quantivalence** of an element or compound radical is its value in chemical exchange measured in terms of hydrogen atoms.

> The atoms of elements are said to be either mono-valent, di-valent, tri-valent, tetra-valent, penta-valent or hexa-valent, according as one atom will unite with or displace one, two, three, four, five or six atoms of hydrogen or chlorine.

11. The Specific Gravity of a Solid or Liquid is the ratio of its absolute weight to the absolute weight of the same volume of water under the same conditions.

12. The Specific Gravity of a Gas is the ratio of the absolute weight of a certain volume of the gas to the absolute weight of the same volume of air under the same conditions of temperature and pressure.

13. The Comparative Density of Gas or Vapour is its weight compared with the weight of an equal volume of hydrogen under the same conditions of temperature and pressure.

14. The Density *of every compound* in the gaseous state is half its molecular weight; or the molecule of a gas occupies the same volume as is filled by two parts by weight of hydrogen.

15. The Boiling point of a Liquid is the temperature at which the tension of the vapour produced is equal to the superincumbent pressure. Thus, then, the boiling-point varies with the pressure, the greater the pressure the higher the temperature of the boiling-point, the less the pressure the lower the temperature at which the liquid boils.

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3.—NOTATION AND ATOMICITY.

1. **Symbols** are the signs or characters used by chemists to represent atoms of **elements**. The symbol of a body is usually the first letter of its English or Latin name, thus—

O stands for one atom of oxygen, and K (Kalmium) potassium.

In cases where the names of several elements commence with the same letter, the first letter is used for the most important, and for the others some prominent letter is added to the first, thus—

C is the symbol for	Carbon,	**Cu** is the symbol for	Copper (cuprum).		
Cl ,, ,,	Chlorine,	**Cd** ,, ,,	Cadmium.		
Cr ,, ,,	Chromium,	**Ce** ,, ,,	Cerium.		
Ca ,, ,,	Calcium,	**Co** ,, ,,	Cobalt.		

In some cases we make use of the distinctive letters of the Latin names, thus, in the list given below, see silver and sodium—

Sulphur is represented by the symbol			**S.**
Silicon	,,	,,	**Si.**
Selenium	,,	,,	**Se.**
Strontium	,,	,,	**Sr.**
Scandium	,,	,,	**Sc.**
Silver (*Argentum*)	,,	,,	**Ag.**
Sodium (*Natrium*)	,,	,,	**Na.**

Again, **F** is the symbol for Fluorine.
Fe ,, ,, Iron (*Ferrum*).

The symbol not only denotes to the chemist the particular element and one atom of the body, but also one atomic weight's worth.

Thus—**H** the symbol for Hydrogen means one atom, and 1 part by weight.

Cl	,,	,,	Chlorine	,,	,,	35·5	,,
O	,,	,,	Oxygen	,,	,,	16	,,
S	,,	,,	Sulphur	,,	,,	32	,,

This, because one atom of chlorine weighs thirty-five and a half times as much as an atom of hydrogen, and the atoms of oxygen and sulphur weigh respectively sixteen and thirty-two times as much as an atom of hydrogen under like conditions. Of the gaseous elements the symbol also denotes one volume, thus, then :—

H stands for *one atom, one volume, and* 1 *part by weight of Hydrogen.*

O	,,	,,	16	,,	,,	*Oxygen.*
Cl	,,	,,	35·5	,,	,,	*Chlorine.*
N	,,	,,	14	,,	,,	*Nitrogen.*

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2. Atomicity, valency or equivalence is the atom fixing power of body measured in terms of an atom of hydrogen. Thus, atoms are said to be *mon-*, *di-*, *tri-*, *tetra-*, *penta-*, and *hexa-valent*, according as they will fix or replace one, two, three, four, five, or six atoms of hydrogen respectively. For the valencies of the elements, the student must refer to table 1, pages 114 and 115.

Thus, the atom of chlorine is monovalent because it will combine with or displace one atom of hydrogen. In hydrochloric acid (HCl) chlorine combines with one atom of hydrogen; and one atom of hydrogen of marsh gas (CH_4) is displaced by one atom of chlorine to form methyl chloride.

Thus—Cl combines with H to form HCl.

Cl acts upon CH_4 to form CH_3Cl and HCl.

Sodium is a monad, calcium a diad, and bismuth a triad; for example:—Na acts upon H_2SO_4 to form $NaHSO_4$ and H_2O; and Ca acts upon H_2SO_4 to form $CaSO_4$ and H_2O.

When a monad conbines with a diad, two atoms of the former combine with one atom of the latter, thus, H_2O, Na_2O are examples in which the diad oxygen atom in each case fixes two monad atoms, hydrogen in water (H_2O) and monad sodium in sodic oxide (Na_2O). When a diad combines with another diad, one atom combines with one atom, thus, in CaO, MgO, calcic and magnesic oxides; we have only one atom of each substance in the molecule of the compound.

The atomicity of a body is usually indicated thus:—

H', Na';	O'' Ca'';	B''', As''';	C^{iv}, Mn^{iv};	N^{v}, Sb^{v};	Se^{vi}, Fe^{vi};
monads.	diads.	triads.	tetrads.	pentads.	hexads.

3. A compound radical is a group of atoms which plays the part of an element in chemical reactions; they are unsaturated compounds with unsatisfied or free bonds, and are spoken of as mono-, di-, tri-, tetra-, penta-, and hexa-valent.

Thus, hydroxyl (hydrogen monoxide) is monovalent and carbonyl (carbon monoxide) is divalent.

The valency of a compound radical is indicated thus:—$(HO)'$ $(CO)''$ $(NaO)'$

In **organic chemistry**, compound radicals are largely employed in building up constitutional formulæ; and such an important part do these unsaturated groups of atoms play in this branch of chemistry that it has been called the **chemistry of the carbon radicals.**

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4. **Formulæ** are used by chemists to represent the kinds of atoms present in the molecules of **compounds**. Thus, HCl is the formula for hydrochloric acid, and it implies that one molecule of that body contains hydrogen and chlorine.

The molecules of the elements usually contain two atoms, and they are represented, for example, thus:—

H_2, O_2, Cl_2, N_2, Si_2, Fe_2, etc.

5. **An empirical formula** represents the **relative** proportion of atoms present in a molecule of a compound, thus:—

H_2CO	is the empirical formula	for	acetic acid.
HCO_2	,,	,,	oxalic acid.
HgCl	,,	,,	mercurous chloride.

6. **A molecular formula** expresses the **absolute** number of atoms in a molecule of any compound body. Thus, whilst the empirical formula for acetic acid, as given above, informs us that one molecule of that body contains hydrogen, carbon, and oxygen in the proportion of two atoms, one atom and one atom. Experiments demonstrate that the molecule is really built up of $H_4C_2O_2$ in which the atomic proportion is 4 : 2 : 2, *i.e.*, 2 : 1 : 1. The more exact and real method of writing the molecule of acetic acid is therefore $H_4C_2O_2$.

Oxalic acid really contains eight atoms in its molecule, and although the proportion of H : C : O is as 1 : 1 : 2, the molecular formula representing the absolute number of atoms in the molecule is $H_2C_2O_4$. Experiments lead us also to the conclusion that the molecule of mercurous chloride is really composed of four atoms and not two, so that its molecular formula is Hg_2Cl_2 and not HgCl.

We see then, that whilst the empirical formula for a body shows us the relative proportion in which the atoms are present, the molecular formula indicates the absolute number of atoms present in a molecule.

In inorganic bodies, as a rule, the empirical and molecular formulæ are identical; for example, both the empirical and molecular formulæ for potassic chlorate are $KClO_3$, and this denotes that one molecule of that body contains one atom of potassium, one of chlorine, and three of oxygen

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But several organic substances have often the same empirical formulæ and the differences between the bodies are represented chemically by the molecular formulæ, thus :—

The empirical formula for acetylene, and benzene is CH, but the molecular formulæ are respectively—C_2H_2 acetylene, C_6H_6 benzene.

A large figure placed before a formula denotes the number of molecules present, thus, $3H_2SO_4$ means three molecules of sulphuric acid, which contain six atoms of hydrogen, three atoms of sulphur, and twelve of oxygen.

7. **A constitutional formula** is intended to show how the molecule of a body is built up, thus, the constitutional formulæ for acetic and oxalic acids are respectively—

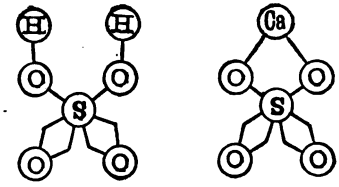
$$\left.\begin{matrix}CH_3\\COHO\end{matrix}\right\}\text{acetic acid.}\qquad\left.\begin{matrix}COHO\\COHO\end{matrix}\right\}\text{oxalic acid.}$$

By this method, we not only show the absolute number of atoms present in the molecule, but the manner in which the compound or elementary radicals present are combined together.

For sulphuric, nitric, and phosphoric acids, the constitutional formulæ are respectively :—$SO_2(HO)_2$, NO_2HO, $PO(HO)_3$.

8. **A graphic formula** is intended to show pictorially how the molecule is constituted, and is therefore, the constitutional formula written graphically. It should show the valency of each element or radical, and account for all the uniting bonds of the same, some examples are given on page 19.

It is advisable in building up the graphic formulæ of salts for the student to start with the formula of the acid from which any particular salt has been derived. For example, calcic sulphate is derived from sulphuric acid in which two atoms of monad hydrogen have given place to one atom of diad calcium.



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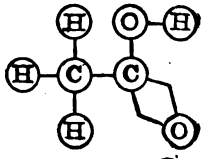
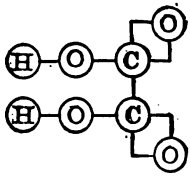
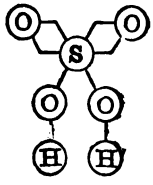
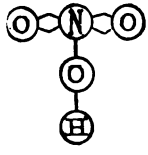
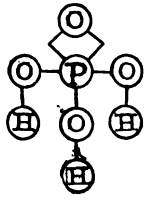
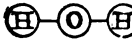
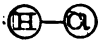
Name.	Empirical Formula.	Molecular Formula.	Constitutional Formula.	Graphic Formula.
Acetic Acid—	CH_2O	$C_2H_4O_2$	CH_3 COHO	
Oxalic Acid—	CHO_2	$C_2H_2O_4$	COHO COHO	
Sulphuric Acid—	H_2SO_4	H_2SO_4	$SO_2(HO)_2$	
Nitric Acid—	HNO_3	HNO_3	NO_2HO	
Phosphoric Acid—	H_3PO_4	H_3PO_4	$PO(HO)_3$	
Potassic Chlorate—	$KClO_3$	$KClO_3$	ClO_2KO	
Water—	H_2O	H_2O	HHO	
Hydrochloric Acid—	HCl	HCl	HCl	

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9. **Oxides**[1] are compounds formed by the union of oxygen with some other element. The oxides form a very numerous and important group of bodies, which may first be broadly divided into two classes:—

(*a*) *Those formed by the union of oxygen with a non-metallic element.* These oxides usually form with water bodies having more or less clearly marked acid properties.

Thus—$SO_2 + H_2O = H_2SO_3$ Sulphur*ous* acid
$SO_3 + H_2O = H_2SO_4$ Sulphur*ic* acid.

The members of this class are often spoken of as acid-forming oxides.

(*b*) *Those formed by the union of oxygen with a metal.* These bodies, as a rule, possess more or less basic characteristics; many form with water the substances known as basic hydrates, thus—

$$K_2O + H_2O = 2KHO.$$

10. **Acids** are bodies which usually have a sour taste and which redden moist blue vegetable colouring matters; they neutralize alkalies forming salts. All acids contain one or more replaceable atoms of hydrogen in each molecule. They are divided into two groups, those containing oxygen, called *oxy-acids*, and those in which oxygen is not present, *hydracids*.

Further, all acids are arranged in classes according to the number of atoms of replaceable hydrogen which they contain, thus—

(*a*) *Monobasic Acids*, those containing one atom of replaceable hydrogen, HCl, HBr, HI, HNO_3.

(*b*) *Dibasic Acids*, those containing two atoms of replaceable hydrogen, H_2SO_4, H_2SO_3, H_2CO_3, H_2S, $H_2C_2O_4$.

(*c*) *Tribasic Acids*, those containing three atoms of replaceable hydrogen, H_3AsO_4, H_3AsO_3, H_3PO_4, $H_3FeC_6N_6$.

(*d*) *Tetrabasic Acids*, those containing four atoms of replaceable hydrogen, H_4SiO_4, $H_4P_2O_7$.

[1] For a Table of the most important of these bodies, see Appendix II., pages 116 and 117.

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11. Bases are bodies which have the power of displacing partly or entirely the replaceable hydrogen of a free acid.

They are usually divided into three classes :—

(*a*) *Metallic Oxides*, such as BaO, CaO, Fe_2O_3, CuO.

(*b*) *Metallic Hydrates*, such as NaHO, KHO, $Ca(HO)_2$.

(*c*) *Certain compounds of hydrogen*, with *nitrogen*, *phosphorus*, *carbon*, *arsenic*, and *antimony*, the most common being NH_3.

12. Salts are bodies which are formed when an acid unites with and is partly or entirely neutralized by a base.

Haloid Salts are yielded by hydracids, for example NaCl.

Oxy-salts are yielded by oxy-acids, such as Na_2SO_4.

Normal Salts are those in which a base has taken the place of all the replaceable hydrogen Na_2SO_4.

Acid Salts are those which still contain some replaceable hydrogen $NaHSO_4$.

4.—CHEMICAL EQUATIONS.

1. Chemical Equations are employed to represent chemical changes, the symbols or formulæ of the bodies employed are placed on the left of the sign =, which implies here, "yields;" and the resulting substances are represented by formulæ and symbols placed on the right; the sign + is employed in the sense of "acted upon by" or "reacting with" thus :—$Na + H_2O = NaHO + H$, means that one atom of sodium acting upon one molecule of water, yield one molecule of sodic hydrate and one atom of hydrogen.

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The following examples of reactions between acids and bases showing the formation of salts should make the matter clear to the student.

Base	Reacting with Acid	Yields Water and	Salt.	Name.
(*a*) KHO	+ HCl	= H_2O +	KCl	*Chloride of monad metal.*
(*b*) $Ca(HO)_2$	+ 2HCl	= $2H_2O$ +	$CaCl_2$	*Chloride of diad metal.*
(*c*) NaHO	+ H_2SO_4	= H_2O +	$NaHSO_4$	*Acid sulphate.*
(*d*) 2NaHO	+ H_2SO_4	= $2H_2O$ +	Na_2SO_4	*Normal sulphate.*
(*e*) NaHO	+ H_3PO_4	= H_2O +	NaH_2PO_4	*Monobasic or diacid phosphate.*
(*f*) 2NaHO	+ H_3PO_4	= $2H_2O$ +	Na_2HPO_4	*Dibasic or monacid phosphate.*
(*g*) 3NaHO	+ H_3PO_4	= $3H_2O$ +	Na_3PO_4	*Tribasic phosphate.*
(*h*) $Ca(HO)_2$	+ $2HNO_3$	= $2H_2O$ +	$Ca(NO_3)_2$	*Nitrate of diad metal.*
(*i*) $Ca(HO)_2$	+ H_2SO_4	= $2H_2O$ +	$CaSO_4$	*Sulphate of diad metal.*
(*j*) NH_4HO	+ HNO_3	= H_2O +	NH_4NO_3	*Nitrate of monad radicle.*

2. Nitrates are salts formed by the substitution of a base or metal for the hydrogen in HNO_3. In the case of a diad element two molecules of HNO_3 are necessary, and with a triad three.

List of more Important Nitrates.	
Hydrogen nitrate	$H'NO_3$
Nitrate of a monad metal (M')	$M'NO_3$
,, ,, diad ,, (M")	$M''(NO_3)_2$
,, ,, triad ,, (M"')	$M'''(NO_3)_3$
,, of metal with n^{th} atomicity (M^n)	$M^n(NO_3)_n$
Argentic nitrate (silver)	$Ag'NO_3$
Barium ,,	$Ba''(NO_3)_2$
Bismuth ,,	$Bi'''(NO_3)_3$

Salts of this series may be formed by the *direct action of free nitric acid on a metal,*

$$\text{thus} - 3\,Cu + 8HNO_3 = 4H_2O + 2NO + 3Cu(NO_3)_2.$$

This equation expresses the fact that metallic copper reacts with nitric acid and yields water, nitric oxide gas, and the salt, copper *nitrate.* In some cases a *basic hydrate may combine with the acid;* thus, for example,

$$KHO + HNO_3 = KNO_3 + H_2O,$$

where potassic hydrate reacts with nitric acid and forms the salt potassic *nitrate* and water.

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3. **Sulphates** are salts in which a base or bases have displaced one, or the two atoms of hydrogen present in a molecule free sulphuric acid.

List of more Important Sulphates.	
Hydrogen sulphate	$H_2'SO_4$
Normal sulphate with monad metal ...	$M_2'SO_4$
,, ,, ,, diad ,, ...	$M''SO_4$
,, ,, ,, triad ,, ...	$M_2'''(SO_4)_3$
Acid ,, ,, monad ,, ...	$M'H'SO_4$
Double salt with monad metals	$M'N'SO_4$
Acid potassic sulphate	$K'H'SO_4$
Potassium ,, ...	$K_2'SO_4$
Calcium ,, ...	$Ca''SO_4$
Aluminium ,, ...	$Al_2'''(SO_4)_3$

Thus the *metal* zinc *may displace the hydrogen* of hydric sulphate with the formation of the salt, zincic *sulphate*, as shown in the following equation :— $Zn + H_2SO_4 = ZnSO_4 + H_2$.

A *basic hydrate may neutralize the acid* partially, as shown in equation (*a*) in which case the acid salt sodic hydric *sulphate* is produced, or entirely as shown in (*b*) where the neutral salt iodic *sulphate* is produced :—

(*a*) $NaHO + H_2SO_4 = NaHSO_4 + H_2O$.

(*b*) $2NaHO + H_2SO_4 = Na_2SO_4 + 2H_2O$.

4. **Chlorides** are the *haloid salts* which are produced when hydrochloric acid is neutralized by a base. These bodies are also formed by the direct action of chlorine on metals, etc. For example, the base lime may act upon hydrochloric acid to form calcic *chloride* and water according to the following equation :—

$$CaO + {}_2HCl = CaCl_2 + H_2O,$$

and chlorine gas may directly act upon sodium to form sodic *chloride* as shown by the following equation :—

$$Na + Cl = NaCl.$$

List or more Important Chlorides.	
Hydrogen Chloride	HCl
Chloride of a monad metal (M′)...	M′Cl
,, ,, diad ,, (M″).....	$M''Cl_2$
,, ,, triad ,, (M‴)	$M'''Cl_3$
,, ,, metal with n^{th} atomicity Mn ...	M^nCln
Argentic Chloride	Ag′Cl
Calcic ,, ...	$Ca''Cl_2$
Ferric ,, ...	$Fe_2'''Cl_6$

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5.—IMPORTANT CHEMICAL LAWS.

1. The Law of the Conservation of Mass.—On the chemical union of two substances their *original weight remains unchanged.*

2. The Law of Constant Proportions.—Every chemical compound contains the simple substances of which it is composed in one and only *one proportion by weight.* (Page 32).

3. The Law of Reciprocal Proportions.—The proportion in which two bodies *A* and *B* unite with a third, *C*, is also the proportion in which they unite with one another as well as with all other bodies.

4. The Law of Multiple Proportions.—The elements combine with each other in a *fixed and definite proportion* by weight or in some simple multiples of these simple proportions.

5. The Law of Volume.—(*a*) The *volumes of two gases* uniting chemically with one another are always in some simple proportion, and the volume of the compound produced, when gaseous, is always in some simple proportion to those of its constituents. (Page 42).

(*b*) The *Weights* of the combining volumes of the gaseous elements bear a simple relation to their atomic weight.

6. Avogadro's Law.—(*a*) Equal volumes of all gases, elementary and compound, contain an equal number of molecules. It follows from this that the molecular weight of gases, under the same conditions, must occupy equal volumes, or the *molecular weight* must be *in the same proportion as the density.* (Page 49).

(*b*) The molecular weights of normal gases in grams occupy 22·32 litres.

(*c*) Whatever number of atoms of different elements in the state of gas or vapour unite to form a molecule, this resulting molecule always occupies in the gaseous state the same space as is occupied by one molecule of hydrogen under like condition, *i.e.*, *two volumes.*

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7. **Boyle's Law.**—The volume of every perfect gas is inversely proportional to the pressure to which it is subjected (see page 64).

8. **Gay-Lussac Law.**—All perfect gases when heated expand $\frac{1}{273}$ of their volume measured at 0°C for each increase, and contract $\frac{1}{273}$ of their volume measured at 0°C for each decrease of 1°C (see page 60).

9. **Charles' Law.**—The pressure remaining the same, the volume of any gas or mixture of gases varies directly as the absolute temperature (see page 60).

10. **Graham's Law.**—Gases diffuse into one another inversely as the square roots of their densities. (Page 68).

11. **Dulong and Petit's Law.**—The specific heat of an element in the solid condition multiplied by its atomic weight yields a constant, called its "atomic heat." (Page 71).

12. **Raoult's Law.**—The molecular weight (in terms of any unit) of any substance dissolved in 100 times the molecular weight (in terms of the same unit) of any solvent, lowers the freezing point of that solvent ·62°C (see page 75).

13. **Mitcherlich's Law.**—Substance of an analogous chemical composition are isomorphous and replace each other in a crystal in every proportion.

14. **Mendelejeff's Law.**—The physical and chemical properties of every element are functions of its atomic weight.

15. **Wurtz' Law.**—The valency of a group of elements is equal to the number of atoms of hydrogen or chlorine, which the saturated compound has lost.

16. **Henry's Law.**—The quantity of any gas absorbed by a given quantity of a liquid is proportional to the pressure.

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II.—DENSITY AND SPECIFIC GRAVITY.

1. The Density of a body is the mass of the unit of volume. Therefore if M denotes the mass, V the volume, and D the density of a body, then M = VD.

The density of a body is usually measured by the number of pounds in one cubic foot of it. If now we take the density of pure water at 4°C to be unity, the relative density of any other substance is the ratio which the mass of any given volume of that substance bears to the mass of an equal volume of water placed under the same conditions of temperature and pressure. The mass of any volume of platinum is 22·069 times that of an equal volume of water under the same conditions, consequently the relative density of platinum is 22·069, or we may say platinum is 22·069 times as dense as water.

The comparative or relative density of a substance is called its *Specific Gravity* (sp. gr.)

2. The Specific Gravity of a Solid or Liquid is the ratio of its absolute weight to the absolute weight of an equal volume of water under the same conditions.

The standard adopted in England is one cubic foot of pure water at 4°C. The sp. gr. therefore of a solid or liquid denotes how many times heavier or lighter it is than an equal volume of water at 4°C.

Since a cubic foot of distilled water at 4°C. is taken as the standard of sp. gr. of solids and liquids, and since also this volume of water weighs 62·425 lbs. about 1,000 ozs., it necessarily follows that the density of a substance is nearly 62·4 times its sp. gr.

The specific gravity of water is 1, its density is $(62{\cdot}4 \times 1) = 62{\cdot}4$.

The specific gravity of mercury is 13·35, its density $(62{\cdot}4 \times 13{\cdot}35) = 833{\cdot}04$.

In French measures the unit of volume is the litre or cubic decimetre of pure water at 4°C, the unit of mass the kilogramme.

EXAMPLE 1.—Eight cu. ft. of copper are found to weigh 71,200 oz. What is the specific gravity of copper?

1 cu. ft. of water weighs 1,000 oz.

$\therefore$ 8 ,, ,, ,, 8,000 oz.

$$\therefore \text{Sp. gr. of copper} = \frac{71200}{8000} = 8{\cdot}9.$$

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EXAMPLE 2.—The specific gravity of mercury is 13·35. What is the weight of a volume of 432 cubic inches of mercury?

1 cu. ft. of water weighs 1000 oz.

$\therefore$ 1 cu. in. ,, ,, $\frac{1000}{1728}$ oz.

$\therefore$ 432 ,, ,, ,, $\frac{1000 \times 432}{1728}$ oz.

$= 250$ oz.

$\therefore$ the weight of 432 cubic inches of mercury is $13{\cdot}35 \times 250 = 3337{\cdot}5$ oz.

EXAMPLE 3.—The specific gravity of copper being 8·9, what volume will 5 tons of copper occupy?

We must first find the volume of 5 tons of water.

5 tons of water $= (5 \times 20 \times 112 \times 16)$ oz.

1000 oz. of water occupy 1 cu. ft.

1 oz. of water occupy $\frac{1}{1000}$ cu. ft.

$(5 \times 20 \times 112 \times 16)$ oz. of water occupy $\frac{(5 \times 20 \times 112 \times 16)}{1000}$ cu. ft.

$= 179{\cdot}2$ cu. ft.

But copper is 8·9 times heavier than water.

$\therefore$ volume of copper $= \frac{179{\cdot}2}{8{\cdot}9} = 20{\cdot}13$ cu. ft.

20·13 cu. ft. is the volume occupied by 5 tons of copper.

The following formula is important: $W = VS$.

$W =$ Weight of body.

Where $V =$ Volume of body in cubic feet.

$S =$ specific gravity.

1 cubic foot of water weighs 1000 oz.

$\therefore$ V cubic feet of water weigh $V \times 1000$ oz.

$$\therefore S = \frac{\text{weight of body}}{\text{weight of equal volume of water}} = \frac{\text{weight of body}}{V \times 1000 \text{ oz.}}$$

3. **The Specific Gravity of a Gas**, *i.e.*, its relative density, is the ratio of the absolute weight of a certain volume of the gas to the absolute weight of the same volume of air under the same conditions of pressure and temperature.

Air being taken as the unit of comparison, the specific gravity of hydrogen is ·0693, for air is bulk for bulk under the same conditions 14·42 times heavier than hydrogen.

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Specific gravity of air = 1,

" " H = ·0693 = $\frac{1}{14{\cdot}42}$.

" " O = 1·1088 = $\frac{16}{14{\cdot}42}$.

" " N = ·9702 = $\frac{14}{14{\cdot}42}$.

" " NH_3 = ·5890 = $\frac{8.5}{14{\cdot}42}$.

" " HCl = 1·2540 = $\frac{18{\cdot}25}{14{\cdot}42}$.

" " CO_2 = 1·5246 = $\frac{22}{14{\cdot}42}$.

The weight of one litre of normal air = 1·293 grams. To find the mass in grains therefore of one litre of any gas if the specific gravity compared with air is given, multiply the given sp. gr. by 1·293, and this will give the answer in grams.

4. Air was formerly taken as the unit of comparison for gases and vapours; but, hydrogen (being the lightest known substance) is a much more convenient body to use as a standard of comparison for elastic fluids.

A certain volume of hydrogen gas under fixed conditions is now generally used as the unit of comparison.

5. **The Comparative Density of a Gas or Vapour** is therefore its weight compared with the weight of an equal volume of hydrogen under the same conditions of pressure and temperature.

The Unit of Volume for gases and vapours is one litre (1,000 cc.) of hydrogen gas at 0°C and 760 mm. barometric pressure.

The weight of this unit of volume is called a **crith** = ·0896 grams.

The crith, then, is the unit of mass, and the **density of a gas** is equal to the number of criths contained in the unit of volume, (one litre at 0°C and 760 mm.)

6. **The Mass**, therefore, of any normal gas may be found by multiplying its density by ·0896, the actual weight of one crith, *i.e.*, one litre of normal hydrogen.

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The densities of the elementary gases, with few exceptions, are expressed by the same numbers as their atomic weights; and those of most compound gases are indicated by the same numbers that represent half their molecular weights.

Thus—

Gas.	Density.	Weight of 1 litre at N.T.P.	Mass of 1 litre at N.T.P.	Atomic Weight.	Molecular Weight.
H	1	1 crith	·0896 grams	1	2
O	16	16 ,,	1·4336 ,,	16	32
N	14	14 ,,	1·2544 ,,	14	28
CO_2	22	22 ,,	1·9712 ,,	...	44
NH_3	8·5	8·5 ,,	·7616 ,,	...	17
HCl	18·25	18·25 ,,	1.6352 ,,	...	36·5

RULE.—*To find the mass in grams of 1 litre of any normal gas, multiply its density by ·0896.*

For example—the density of N is 14.

∴ the mass in grams of 1 litre N, is (14 × ·0896) = 1·2544 grams.

Again—the density of CO_2 is 22.

∴ the mass in grams of 1 litre CO_2 is (22 × ·0896) = 1·9712.

7. It appears that the molecules of some substances are broken up at a temperature near to their boiling points, in consequence of which they form vapours having abnormal densities.

TABLE OF MORE IMPORTANT BODIES WITH ABNORMAL DENSITIES.

Symbol.	Element.	Molecular Weight.	Density.
Hg	Mercury	200	100
Cd	Cadmium	112	56
P	Phosphorus	124	62
As	Arsenic	300	150
S	Sulphur *(below 600°C.)*	192	96

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EXAMPLE 4.—If 100 cubic inches of air weigh 31 grains, find the weight of 10 cubic feet of hydrogen of Sp.gr. ·0693, that of air being 1, at the same temperature and pressure.

Weight of 100 cubic inches of air = 31 grains.

" 1 cubic inch " = $\frac{31}{100}$ "

" 17,280 cubic inches of air = $\frac{31 \times 17280}{100}$.

" 17,280 " hydrogen = $\frac{31 \times 17280}{100} \times ·0693$ = 371·22624 grains.

EXAMPLE 5.—A flask full of air weighs 1250 grains; when empty it weighs 250 grains, and when full of ammonia gas 839 grains. What is the specific gravity of ammonia?

Sp.gr. of ammonia = $\frac{\text{weight of gas in flask}}{\text{weight of air in flask}} = \frac{839 - 250}{1250 - 250} = ·589$.

QUESTIONS I.

1. Find the specific gravity of a body of which 3 cubic feet weigh 5,000 oz.
2. Find the specific gravity of a substance of which 8·75 tons occupy 16 cubic yards.
3. 16 cubic feet of copper weigh 142,400 oz. What is the specific gravity of copper?
4. The specific gravity of mercury is 13·35. What will 432 cubic inches of mercury weigh?
5. What is the weight, in grams, of 25 litres of phosphine gas?
6. What is the mass of 316 litres of hydrogen measured at 0°C and 760 mm. pressure?
7. What is the mass of 556 cubic centimetres of oxygen gas measured at 0°C and 760 mm. pressure?
8. How much will 1 litre of chlorine gas weigh at 0°C and 760 mm.?
9. What is the weight of 1 litre of each of the following gases at 0°C and 760 mm. pressure—Nitrogen, Hydrochloric Acid, Nitrogen Monoxide?
10. Find the weight of one litre of (*a*) Phosphorus trihydride, (*b*) Nitrogen tetroxide, at normal temperature and pressure?

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III.—MOLECULAR WEIGHT FROM FORMULA.

1. From the symbol or formula of a substance to find its Molecular Weight.

1. *The molecular weights of the elements are, with certain exceptions, equal to twice the atomic weights.*

Thus, molecular weight of Hydrogen - H_2 = (1 × 2) = 2
,, ,, Oxygen - O_2 = (16 × 2) = 32
,, ,, Chlorine - Cl_2 = (35·5 × 2) = 71
,, ,, Bromine - Br_2 = (80 × 2) = 160
,, ,, Potassium - K_2 = (39·1 × 2) = 78·2
,, ,, Mercury - Hg = (200 × 1) = 200
,, ,, Cadmium - Cd = (112 × 1) = 112
,, ,, Arsenic - As_4 = (75 × 4) = 300
,, ,, Phosphorus - P_4 = (31 × 4) = 124
(Below 600°C) ,, ,, Sulphur - S_6 = (32 × 6) = 192

2. *The molecular weight of a compound is equal to the sum of the numbers representing the weights of the constituent atoms.*

Thus the molecular weight of HCl is (1 + 35·5) = 36·5
,, ,, ,, NH_3 is $\{14 + 3(1)\}$ = 17
,, ,, ,, H_2SO_4 is $\{2(1) + 1(32) + 4(16)\}$ = 98

RULE:—

(*a*) *Write down the formula.*

(*b*) *Find from the tables, in the Appendix, the combining or atomic weights of the component elements.*

(*c*) *Then multiply each of these numbers by the number of atoms present in one molecule.*

(*d*) *Lastly, add together the numbers representing the weights of the constituent atoms.*

EXAMPLE.—Find the molecular weight of K_2CrO_4.

K = 39·1 ∴ K_2 = (39·1 × 2) = 78·2
Cr = 52 ∴ Cr = (52 × 1) = 52·0
O = 16 ∴ O_4 = (16 × 4) = 64·0

∴ the molecular weight of K_2CrO_4 is 194·2

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QUESTIONS II.

11. Find the molecular weight of water, hydrochloric acid and nitrous oxide.

12. What is the molecular weight of each of the following bodies :— nitric acid, ammonia, carbon monoxide?

13. What do you understand by the molecular weight of a body, and calculate the molecular weight of each of the following substances :—sulphuretted hydrogen, and hydroiodic acid?

14. Describe fully how you arrive at the molecular weight of a body, and calculate the molecular weights of sulphuric acid and sulphur-dioxide.

15. What are the molecular weights of potassic chlorate, common salt, and calcic chloride?

16. Calculate the molecular weights of each of the following:— ammonic sulphate, potassic hydrate, and calcic hydrate.

17. Find the molecular weight of bodies having the following formulæ :—Al_2O_3 and $BaSO_4$.

18. What is the molecular weight of each of the following bodies :— $Al_2K_2(SiO_3)_4$, Sb_2O_5, and $PbCrO_4$?

19. Show how you would determine the molecular weight of each of the following substances :—$Al_6Ca_4H_2(Si_3O_{12})_2$, $(BiO)_2Cr_2O_7$.

20. Calculate the molecular weight of NH_4NO_3, $Fe_2(AsO_4)_2$, $BaSO_4$, $Na_2H_2Sn_6O_{12}$, Fe_2Cl_6, and write down the name of each substance.

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IV.—PERCENTAGE COMPOSITION AND PROPORTION WEIGHTS.

1. To find the Percentage Composition of a body or the number of parts by weight of each element in one hundred parts by weight of a given compound.

RULE:—

(a) Write down the formula of the body.
(b) Find the molecular weight.
(c) Find the proportion of each element in 100 parts.

EXAMPLE.—Find the percentage composition of carbon dioxide thus:—

(a) Formula CO_2.
(b) Molecular Weight $12 + 2(16) = 44$.

Since 44 parts by weight of CO_2 contain 12 parts by weight of C.

$$\therefore \quad 1 \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad \frac{12}{44} \quad \text{,,} \quad \text{,,}$$

$$\therefore \quad 100 \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad \frac{100 \times 12}{44} \quad \text{,,} \quad \text{,,}$$

$$= 27{\cdot}27 \text{ per cent. of carbon.}$$

Again—since 44 parts by weight of CO_2 contain 32 parts by weight of O.

$$\therefore \quad 1 \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad \frac{32}{44} \quad \text{,,} \quad \text{,,}$$

$$\therefore \quad 100 \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad \frac{32 \times 100}{44} \quad \text{,,} \quad \text{,,}$$

72·73 per cent. of oxygen.

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2. To find the Weight of an element contained in a given weight of some body.

RULE :—

(*a*) *Write down the formula of the body.*

(*b*) *Write down the proportion by weight of each element in the molecule.*

(*c*) *Find the molecular weight.*

(*d*) *Find the proportion of the required element in the given weight.*

EXAMPLE.—How much chlorine is there in 10 lbs. of common salt?

(*a*) Formula is NaCl.

(*b*) Proportionate amount of Cl in the molecule is 35·5.

(*c*) Molecular weight of NaCl is $23 + 35{\cdot}5 = 58{\cdot}5$.

Now, 58·5 parts by weight of NaCl contains 35·5 parts by weight of Cl.

∴ 1 part ,, ,, ,, $\frac{35{\cdot}5}{58{\cdot}5}$,, ,,

∴ 10 parts ,, ,, ,, $\frac{35{\cdot}5 \times 10}{58{\cdot}5}$,,

$= 6{\cdot}068$ lbs. of Cl.

∴ 10 lbs. of salt contain 6·068 lbs. of Cl.

QUESTIONS III.

Find the percentage composition of—

21.	Manganese dioxide	MnO_2.
22.	Silver chloride	AgCl.
23.	Potassic iodate	KIO_3.
24.	Potassic chromate	K_2CrO_4.
25.	Zincic sulphate	$ZnSO_4$.
26.	Cupric sulphate	$CuSO_4$.
27.	Cupric nitrate	$Cu(NO_3)_2$.
28.	Potassic permanganate	$KMnO_4$.
29.	Calcium carbonate	$CaCO_3$.
30.	Potassic nitrate	KNO_3.
31.	Nitrous acid	HNO_2.
32.	Nitric acid	HNO_3.
33.	Ammonic nitrate	NH_4NO_3

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34. How much oxygen is there in 100 lbs. of Mercuric oxide HgO?
35. Find the percentage composition of Potassic hydric sulphate.
36. What is the percentage composition of Nitric tetroxide N_2O_4?
37. What is the percentage composition of Hypochlorous acid HClO?
38. 1867. E.—In 100 parts by weight of common salt how many parts by weight of chlorine?
39. 1869. E.—What is the percentage composition of a substance, the formula of which is $N_2O_2H_4$?
40. 1871. E.—How much, by weight, of each element is contained in 100 lbs. of a compound whose formula is $SO_4N_2H_8$?
41. 1872. E.—How much, by weight, of each element is contained in 100 lbs. of a compound whose formula is $P_2O_7N_4H_{16}$?
42. 1874. E.—What is the percentage composition of hydrochloric acid?
43. 1875. E.—What is the percentage composition of water?
44. 1876. E.—What is the percentage composition of ammonic chloride?
45. 1877. E.—How many grains of oxygen are contained in 1 lb. of each of the following compounds:—Water, potassic chlorate, carbonic oxide, and ammonic nitrate?
46. 1878. E.—Calculate the percentage composition of potassium chlorate (chlorate of potash). (K = 39. Cl = 35·37. O = 16).
47. 1884. E.—Describe experiments which show that nitric acid has great oxidising powers. In 100 grams of nitric acid how much is oxygen?
48. 1885. E.—What weight of carbon and oxygen is there in 100 parts by weight of each of the oxides of carbon?
49. 1867. A.—How many grams of phosphorus are required for the production of 100 grams pyrophosphate of magnesium?
50. How much chlorine is there in 50 ozs. of common salt?
51. How many parts by weight of hydrogen does 10 lbs. of water contain?
52. What quantity of nitrogen is there in 25 grams of ammonia gas?
53. How much sodium is there in 15 milligrams of salt?
54. What is the percentage composition of ammonia gas?
55. What is the percentage composition of quick lime?

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V.—TO CALCULATE MASS FROM AN EQUATION.

A Chemical Equation expresses the truth that certain substances when present in definite proportions react upon each other and produce definite quantities of some other substances.

Inasmuch as matter is indestructible, it follows that the sum of the masses of the substances taking part in the reaction must be exactly equal to the sum of the masses of the bodies produced. That is, in every perfect chemical equation, the sum of the numbers representing the weights of the constituent molecules of the substances on one side of the equation, is equal to the sum of the weights of the constituent molecules of the substances on the other side of the equation.

Thus, $H + Cl = HCl$, expresses that 1 part, by weight, of hydrogen combines with 35·5 parts, by weight, of Cl to form 36·5 parts, by weight, of hydrochloric acid gas.

Again –

$$\begin{aligned} 2KClO_3 &= 2KCl + 3O_2. \\ 2(39 + 35{\cdot}5 + 48) &= 2(39 + 35{\cdot}5) + 3(2 \times 16). \\ 245 &= 149 + 96. \end{aligned}$$

expresses that 245 parts, by weight, of potassic chlorate yield when heated 149 parts, by weight, of potassic chloride and 96 parts, by weight, of oxygen.

Again—

$$\begin{aligned} MnO_2 + 4HCl &= MnCl_2 + 2H_2O + Cl_2 \\ (55 + 32) + 4(1 + 35{\cdot}5) &= (55 + 71) + 2(2 + 16) + (35{\cdot}5 \times 2). \\ 87 + 146 &= 126 + 36 + 71 \end{aligned}$$

expresses that when 87 parts, by weight, of manganese dioxide react on 146 parts of hydrochloric acid, there is produced 126 parts of manganese chloride, 36 parts of water, and 71 parts of chlorine, by weight. Further, it will be seen that the sum of the weights on each side of the equation is 233.

1.—To find the weight of a body obtainable from a given weight of some substance.

RULE :—

(*a*) *Write down the equation expressing the reaction.*

(*b*) *Write down the atomic weight of the substances under the symbols.*

(*c*) *Multiply the atomic weight by number of atoms in each case.*

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From these data calculate results thus—

EXAMPLE.—How much oxygen can be obtained from 25 grams of mercuric oxide?

Equation, $HgO + \text{heat} = Hg + O$

$200 + 16 \qquad 200 + 16.$

Since 216 parts, by weight, of HgO yield 16 parts, by weight, of O;

$\therefore$ 216 grams of HgO will yield 16 grams of O;

$\therefore$ 1 " " " $\frac{16}{216}$ " "

$\therefore$ 25 " " " $\frac{25 \times 16}{216}$ " "

$= 1{\cdot}851$ "

25 grams of HgO will yield $1{\cdot}851$ grams of oxygen.

2. To find the weight of a body required to produce a given weight of some substance.

RULE:—

(*a*) *Write down the equation expressing the reaction.*

(*b*) *Write down the weights of the substance under the formulæ*

(*c*) *From these data calculate the results, thus—*

EXAMPLE 1.—How much potassium chlorate shall I require in order to obtain 39·183 grams of oxygen gas?

Equation $2KClO_3 + \text{heat} = 2KCl + 3O_2.$

$2\{39 + 35{\cdot}5 + 3(16)\} + \text{"} = \text{"} + 3(16 \times 2).$

$245 + \text{"} = \text{"} + 96.$

Since 96 parts by weight of oxygen are yielded by 245 parts by weight of $KClO_3$.

$\therefore$ 96 grams oxygen are yielded by 245 grams $KClO_3$.

$\therefore$ 1 " is " $\frac{245}{96}$ "

$\therefore$ 39·183 " are " $\frac{39{\cdot}183 \times 245}{96}$ "

$= 100$ "

$\therefore$ 100 grams of $KClO_3$ yield 39·183 grams of oxygen.

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EXAMPLE 2.—By the action of hydrochloric acid on lime 15 grams of calcium chloride was produced, what weight of lime and hydrochloric acid had been used?

Equation $CaO + 2HCl = CaCl_2 + H_2O.$

$(40 + 16) + 2(1 + 35{\cdot}5) = \{40 + 2(35{\cdot}5)\} +$,,

$56 + 73 = 111 +$,,

Since 111 parts by weight of $CaCl_2$ are produced from 56 parts by weight of CaO and 73 of HCl.

∴ 111 grams $CaCl_2$ would be produced from 56 grams CaO and 73 grams HCl.

∴ 1 ,, ,, ,, $\frac{56}{111}$,, $\frac{73}{111}$,,

∴ 15 ,, ,, ,, $\frac{56\times15}{111}$,, $\frac{73\times15}{111}$,,

$7{\cdot}\dot{5}\dot{6}\dot{7}$,, $= 9{\cdot}\dot{8}\dot{6}\dot{4}$,,

15 grams of $CaCl_2$ are yielded by $7{\cdot}\dot{5}\dot{6}\dot{7}$ grams of CaO, $9{\cdot}\dot{8}\dot{6}\dot{4}$ grams of HCl.

QUESTIONS IV.

56. 1867. E.—How many grams of oxygen can be separated from 100 grams of binoxide of manganese by heat? and how many by the action of sulphuric acid?

57. 1868. E.—How much water would be produced from 28 lbs. of oxygen and 5 lbs. of hydrogen, and would either of the elements be in excess?

58. 1868. E.—You are required to convert 1 lb. of silver into argentic nitrate (nitrate of silver), how will you do it, and what will be the weight of nitrate produced?

59. 1874. E.—How much sulphuric acid may be made from one ton of FeS_2?

60. 1877. E.—How many milligrams of hydrogen are evolved when 460 milligrams of sodium (Na = 23) are thrown into water? Express the decomposition by an equation.

61. 1878. E.—Air contains 23 per cent. of its weight of oxygen. How many grams of phosphorus are needed to burn out the whole of the oxygen in 100 grams of air when the highest oxide of phosphorus is formed? P=31.

62. 1879. E.—How many pounds of nitric acid can be obtained from 150 lbs. of nitre (potassium nitrate) and how many grains of sulphuric acid will be needed?

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63. 1880. E.—If twelve grams of pure carbon be completely burnt in the oxygen which is obtained by decomposing 122·5 grams of potassic chlorate, what is the weight of the product of the combustion formed, and what is the weight, if any, of oxygen remaining?

64. 1881. E.—How many milligrams of hydrogen will be formed (1) when 230 milligrams of sodium are thrown on water (2) when 649 milligrams of zinc are dissolved in sulphuric acid?

65. 1882. E.—What are the materials you would require in making chlorine, and what quantities must be used in order to obtain 1,000 grams of this gas?

66. 1882. E.—What weight of sulphur is required, theoretically, to produce 100 tons of sulphuric acid?

67. 1885. E.—What weight (1) of oxide of mercury, and (2) of manganese dioxide must be used in order to obtain 100 lbs. of oxygen?

68. 1867. A.—The copper is to be precipitated from 100 grams of crystallized sulphate of copper ($CuSO_4 + 5H_2O$) by means of metallic zinc. How much zinc is required?

69. 1868. A.—How much white marble would you require to produce 1 cwt. of chloride of calcium, and what other material would be necessary for the transformation? Express the chemical change by an equation.

70. 1869. A.—Explain the process of manufacturing nitric acid from sodic nitrate (nitrate of soda). What is the theoretical quantity of pure nitric acid obtainable from 1 ton of sodic nitrate?

71. 1881. A.—One gram of gold and 1 gram of platinum are dissolved separately in aqua-regia, give the weight and formula of the gold compound, and of the platinum compound formed.

72. 1881. A.—How many tons of sulphuric acid can theoretically be manufactured from 500 tons of pyrites containing 48 per cent. of sulphur?

73. 1884. A. How many grams of iodine will be liberated from a solution of potassic iodide, into which the gas evolved from heating 4·34 grams of manganese dioxide with hydrochloric acid is passed?

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74. 1885. A.—What weight of potassium bichromate must be heated with hydrochloric acid in order to obtain sufficient chlorine to liberate the iodine from 1,656 grams of potassium iodide?

75. 1886. A.—A solution of nitric acid (sp. gr. 1·46) contains 80 per cent. of HNO_3. What weight of this solution is theoretically required to dissolve 10 grams of copper oxide?

76. What weight of gas can be obtained from 16 grams of calcium carbonate ($CaCO_3$) by heating.

77. What weight of nitrogen can be obtained from 500 grams of air?

78. What weight of hydrochloric acid may be obtained from 15 grams of common salt?

79. What weight of sulphur dioxide can be obtained by burning 25 grams of sulphur in oxygen, and how much oxygen is required for the complete combustion?

80. What weight of ammonia can be obtained from 15 ozs. $(NH_4)_2CO_3$?

81. What weight of chlorine can be obtained from 20 grams of NaCl?

82. How much ammonia can be obtained from 50 grams of sal-ammoniac?

83. How much nitric acid can be obtained from 15 ozs. of KNO_3?

84. How much chlorine is contained in 15 lbs. of calcium chloride?

85. How much ammonic chloride shall I want for the preparation of 28 grams of ammonia?

86. How much salt shall I want for the preparation of 32 grams of hydrochloric acid gas?

87. How many milligrams of sodic chloride are required from the complete precipitation as argentic chloride of the silver in 128 grams of pure dry argentic nitrate ($AgNO_3$)?

88. How many grams of hydrobromic acid may be obtained by the action of 85 grams of bromine on phosphorus and water?

89. I require enough hydrochloric acid to neutralize 75 grams of sodic hydrate. What quantity of common salt must be acted upon by sulphuric acid in order to liberate the required quantity of hydrochloric acid?

90. Sufficient ammonia gas is passed into a solution of 50 grams of dilute hydrochloric acid (containing 40 per cent. of pure hydrochloric acid) to completely neutralize the same. How much sal ammoniac must have been used in the preparation of this quantity of ammonia gas?

91. What weight of ammonia will be required to neutralize 166·6 grams of sulphuric acid (H : O : N : S = 1 : 16 : 14 : 32)?

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VI.—TO CALCULATE VOLUME OF GAS FROM EQUATION.

"The volumes of two gases uniting chemically with one another are always in some simple proportion, and the volume of the compound produced, when gaseous, is always in some simple proportion to those of its constituents."

We owe the discovery of the law given above to the celebrated French chemist, Gay Lussac, after whom it is called.

1. To find the volume of one gas when that of another is given.

Since each molecular weight expresses two volumes, the result may ofter be obtained by mere inspection.

EXAMPLE.—What volume of water gas is produced when ten litres of hydrogen combine with oxygen?

$$H_2 + O = H_2O.$$
1 molecule + 1 atom = 1 molecule.
2 volumes + 1 volume = 2 volumes.

From above two volumes of water gas are produced from two volumes of hydrogen and one volume of oxygen.

∴ 2 litres H_2O gas are produced from 2 litres of H and 1 litre of O.

∴ 10 ,, ,, ,, 10 ,, and 5 litres of O.

2.—To find the volume of a gas produced when the volumes of two other gases are given.

RULE:—

(a) Construct an equation.

(b) Place under the symbols or formulæ for the substances the volumes occupied.

(c) As the proportions are usually simple, the volume produced may be calculated by inspection, or as in examples given on page 43.

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EXAMPLE 1.—How much hydrochloric acid in cubic centimetres is formed by the combination of 25 cc. of Cl and 25 cc. of H?

$$H_2 + Cl_2 = 2HCl.$$
$$2 \text{ vols.} + 2 \text{ vols.} = 4 \text{ vols.}$$

Since from the combination of 2 vols. H with 2 vols. Cl, 4 vols. HCl are produced.

Therefore, from the combination of 2 c.c. H with 2 c.c. Cl, 4 c.c. HCl are produced.

And from the combination of 25 c.c. H with 25 c.c. Cl, 50 C.c. HCl are produced.

EXAMPLE 2.—How much oxygen is required for the complete combustion of 10 cubic inches of marsh gas, and what is the volume of the products in the gaseous state?

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$2 \text{ vols.} + 4 \text{ vols.} = 2 \text{ vols.} + 4 \text{ vols.}$$

Since 2 vols. of marsh gas require 4 vols. O and produce 2 vols. CO_2 and 4 vols. H_2O gas.

2 cu. in. of marsh gas require 4 cu. in. O and produce 2 cu. in. CO_2 and 4 cu. in. H_2O gas.

10 cu. in. of marsh gas require 20 cu. in. O and produce 10 cu. in. CO_2 and 20 cu. in. H_2O gas.

It is important to remember in solving problems of this character that unless the contrary is stated in the question it must be taken for granted that nitrogen is unchanged.

Carbon converted into carbon dioxide.
Sulphur ,, ,, sulphur dioxide.
Hydrogen ,, ,, water-gas or steam.
Phosphorus ,, ,, phosphoric pentoxide.

QUESTIONS V.

92. 1870. E. I add two volumes of oxygen to one volume of each of the following gases; what takes place, and what effect will be produced if an electric spark be afterwards passed through each of the mixtures?

Chlorine	Nitric oxide
Hydrogen	Carbonic oxide
Sulphuretted hydrogen	Carbonic anhydride
Nitrous oxide	

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93. 1877. E.—One volume of carbon monoxide (carbonic oxide) gas is mixed with two volumes of oxygen, and an electric spark passed through the mixture; what volume of carbonic dioxide gas (carbonic anhydride) is formed, and what volume of oxygen left?

94. 1879. E.—A mixture of five volumes of hydrogen and three volumes of oxygen are exploded by an electric spark; will any gas remain? If so, how much, and how will you ascertain what it is?

95. 1881. E.—How many volumes of carbon dioxide (carbonic acid gas) will be formed, when a mixture of four volumes of carbon monoxide (carbonic oxide gas) and four volumes of oxygen is burnt? State what volume of oxygen, if any, remains uncombined.

96. 1882. E.—50 cbc. of oxygen are mixed with 500 cbc. of hydrogen, both measured at the normal temperature and pressure, an electric spark is passed through the mixture; what volume, if any, of gas will remain, and how would you ascertain which it is?

97. 1883. E—300 volumes of carbon monoxide are mixed with 300 volumes of oxygen, an electric spark is passed through the mixture, and then a solution of caustic potash is added; what volume of gas will be absorbed, and of what will the residue, if any, consist?

98. 1885. E.—One hundred volumes of air, containing 21 volumes of oxygen, are mixed with 70 volumes of hydrogen, and an electric spark passed through the mixture; what will be the volume of gas remaining, and of what will it consist?

99. 1867. A.—100 litres of phosphoretted hydrogen (H_3P) at 100°C are mixed with 300 litres of chlorine at 100°C. How many litres of chloride of phosphorus gas and how many litres of hydrochloric acid, both measured at 100°C, are produced?

100. 1870. A—Two volumes of marsh gas, 4 of hydrogen, 1 of nitrogen, 8 of oxygen, are measured at 0°C, and 760 mm. mercurial pressure. They are then mixed together and exploded by the electric spark. What is the volume of the gaseous products at the same temperature and pressure, and what would it be at 200°C?

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101. 1872. A.—I pass an electric spark through each of the following gaseous mixtures, describe exactly what happens in each case :—

1st mixture	2 volumes of oxygen. 1 volume of hydrogen.
2nd mixture	2 volumes of hydrogen. 1 volume of oxygen.
3rd mixture	1 volume of hydrogen. 2 volumes of chlorine.
4th mixture	1 volume of oxygen. 2 volumes of chlorine.

102. 1882. A.—How many volumes of oxygen are required for the complete combustion of 500 volumes of each of the following gases, and how many volumes of CO_2 will in each case be formed? Olefiant gas, acetylene, cyanogen, marsh gas.

103. 1884. A.—What volume of carbon dioxide must be passed over red-hot charcoal to yield 159 litres of carbon monoxide? How would you show that the former gas contains its own volume of oxygen?

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VII.—FROM THE VOLUME OF A GAS TO FIND WEIGHT.

1. To find the Weight of a given volume of a gas at normal temperature and pressure. (N.T.P.)

RULE :—

(*a*) *Write down the symbol or formula.*

(*b*) *Write down the density of the gas.*

(*c*) *Multiply the density by the number of litres given.*

(*d*) *Multiply the product obtained in* (*c*) *by ·0896, this will give the answer in grams.*

EXAMPLE 1.—What is the weight of 8 litres of oxygen at N.T.P.?

(*a*) Formula is O_2.

(*b*) Density is $\frac{32}{2} = 16$.

(*c*) 16×8.

(*d*) $16 \times 8 \times \cdot0896 = 11\cdot4688$.

8 litres of oxygen weigh 11·4688 grams.

EXAMPLE 2.—What is the weight of 5 litres of NH_3 at N.T.P.?

(*a*) Formula is NH_3.

(*b*) Density is $\frac{14 + 3}{2} = \frac{17}{2} = 8\cdot5$.

(*c*) $8\cdot5 \times 5$

d) $8\cdot5 \times 5 \times \cdot0896 = 3\cdot808$.

5 litres of NH_3 weigh 3·808 grams.

2. The volume of a gas being given to find the weight of the substances required to produce it.

RULE :—

(*a*) *Write down the equation expressing the reaction.*

(*b*) *Find the weight of the given volume of gas.*

(*c*) *From these data solve the equation as below.*

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Example 1.—How much phosphorus may be obtained by intensely heating 10 litres of hydrogen phosphide.

(*a*) Equation $2PH_3 = P_2 + 3H_2$.

$2(31 + 3) = (2 \times 31) + 3H_2$.

$68 = 62 + 3H_2$.

(*b*) Density of $PH_3 = \frac{31 + 3}{2} = 17$.

∴ weight of 10 litres of PH_3 is $(17 \times 10 \times \cdot0896)$ grams.

(*c*) From equation above:—

68 grams of PH_3 yield 62 grams of P.

∴ 1 „ „ $\frac{62}{68}$ „

∴ $(10 \times 17 \times \cdot0896)$ „ „ $\frac{62 \times (10 \times 17 \times \cdot0896)}{68}$ „

$= 13\cdot888$ „

10 litres of PH_3 yield 13·888 grams of P.

Example 2.—How much carbon must be burnt in oxygen in order to produce 15 litres of carbon dioxide.

(*a*) Equation $C + O_2 = CO_2$.

$12 + 2(16) = \{12 + 2(16)\}$

$12 + 32 = 44$.

(*b*) Density of $CO_2 = \frac{44}{2} = 22$.

∴ weight of 15 litres of $CO_2 = (15 \times 22 \times \cdot0896)$ grams.

(*c*) From equation above:—

44 grams of CO_2 are produced by burning 12 grams of C.

∴ 1 „ „ „ „ $\frac{12}{44}$ „

∴ $(15 \times 22 \times \cdot0896)$ grams of CO_2 are produced by burning

$\frac{12\ (15 \times 22 \times \cdot0896)}{44}$

$= 8\cdot064$ grams of C.

15 litres of CO_2 are produced by burning 8·064 grams of C.

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QUESTIONS VI.

104. 1868. E.—If a given volume of hydrogen weighs 20 grains, how much will the same volume of carbonic acid gas weigh at the same temperature and pressure?

105. 1869. E.—I take equal volumes, measured at the same temperature and pressure of hydrogen, nitrogen, hydrochloric acid gas, steam, and carbonic anhydride (carbonic acid), and find that the nitrogen weighs 56 grams. Required the weight of each of the other gases.

106. 1870. E.—One litre of nitrogen gas, measured at 0°C, and 760 mm. mercurial pressure, weighs 14 criths; what is the weight in grains of one cubic metre of the same gas measured at the same temperature and pressure?

107. 1873. E.—What is the weight of a litre of a gaseous compound, the molecule of which contains $COCl_2$?

108. 1875. E.—What is the weight of a litre (at 0°C and 760 mm. barometric pressure) of the vapour of a compound, the normal molecule of which contains SO_3?

109. 1880. E.—If 112 litres of hydrogen weigh ten grams, what is weight in grams of the same volume of chlorine, and of the same volume of hydrochloric acid gas?

110. 1872. E.—Where has free hydrogen been observed in nature? A balloon requires 5 cubic metres of gas to inflate it, how many kilograms of sulphuric acid must be converted into zincic sulphate (sulphate of zinc) in order to evolve sufficient hydrogen to fill it?

111. 1871. A.—In dissolving zinc in hydrochloric acid, and collecting the hydrogen evolved, 250 cubic centimetres of the gas measured at 0°C, and 760 mm. pressure were obtained. How much zinc was dissolved?

112. 1873. A.—A piece of sodium was completely converted into chloride by the absorption of 200 cubic centimetres of chlorine measured at 0°C and 760 mm. mercurial pressure; what was the weight of the sodium?

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VIII.—FROM WEIGHT TO FIND VOLUME OF GAS.

1. To find the Volume of a given weight of any gas at N.T.P.

It has been found by experiment that the number which stands for the density of a normal gas expressed in grams represents a volume of 11·16 litres of that gas.

Thus:—

Gas.	At. Wt.	M. Wt.	Density.	
H	1	2	1	∴ 1 gram = 11·16 litres.
O	16	32	16	∴ 16 ,, = 11·16 ,,
N	14	28	14	∴ 14 ,, = 11·16 ,,
HCl	...	36·5	18·25	∴ 18·25 ,, = 11·16 ,,
NH_3	...	17	8·5	∴ 8·5 ,, = 11·16 ,,
CO_2	...	44	22	∴ 22 ,, = 11·16 ,,

RULE:—*Therefore to find the volume, V, from weight, W, divide the weight of the gas by the number representing its density, D, and multiply this quotient by 11·16, which will give the answer in litres.*

$$V = \frac{W}{D} \times 11{\cdot}16.$$

EXAMPLE 1.—What volume will 10 grams of oxygen occupy at N.T.P

$$V = \frac{W}{D} \times 11{\cdot}16.$$

$$= \frac{10}{16} \times 11{\cdot}16.$$

$$= 6.975.$$

volume of 10 grams of O is 6·975 litres.

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Example 2.—What volume will 225 grams of hydrogen sulphide occupy at N.T.P.

$$\text{Density of } H_2S = \frac{2 + 32}{2} = 17.$$

$$V = \frac{W}{D} \times 11{\cdot}16.$$

$$= \frac{225}{17} \times 11{\cdot}16.$$

$$= 147{\cdot}7.$$

225 grams of H_2S at N.T.P. occupy 147·7 litres.

2. The weight of a substance or substances being given to find the Volume of gas produced.

Rule :—

(*a*) *Write down equation.*

(*b*) *Find the weight of the body produced from the given weight of the substance.*

(*c*) *Convert the weight obtained by* (*b*) *into volume as shown below :—*

Example.—From 15 grams of potassium chlorate, how many litres of oxygen can be obtained?

Equation $2KClO_3 = 2KCl + 3O_2.$

$2(39 + 35{\cdot}5 + 48) = \quad + 3(32).$

$245 = \quad + 96.$

Density of oxygen = 16.

∴ 16 grams ,, = 11·16 litres.

∴ 96 ,, (16 × 6) ,, = (6 × 11·16) = 66·96 litres.

From 245 grams of $KClO_3$, 66·96 litres of O are obtained.

,, 1 ,, ,, $\frac{66{\cdot}96}{245}$,, ,, ,,

,, 15 ,, ,, $\frac{15 \times 66{\cdot}96}{245}$,, ,, ,,

$= 4{\cdot}09$,, ,, ,,

4·09 litres of O are obtained from 15 grams of $KClO_3$.

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QUESTIONS VII.

113. 1869. E.—If 50 grams of sodium be heated in a current of hydrobromic acid gas until it is completely converted into sodic bromide (bromide of sodium), what will be the weight and volume of the hydrogen liberated?

114. 1871. E.—How much chlorine, by weight (in grams) and by measure (in cubic centimetres), can I obtain from one litre of hydrochloric acid, measured at 0°C, and 760 millimetres, mercurial pressure?

115. 1879. E.—How many litres of carbon dioxide (carbonic anhydride) will be formed by the complete combustion of 12 grams of carbon, and how many litres of oxygen will be required?

116. 1883. E.—How many litres of oxygen are required to completely burn (*a*) 120 grams of sulphur and (*b*) 155 grams of phosphorus?

117. 1884. E.—How many cubic centimetres of hydrogen can 4·6 grams of sodium liberate from water, the barometer standing at 760 mm. and the thermometer at 0°C (22·4 cubic centimetres of hydrogen weigh 2 milligrams)? Give equation.

118. 1884. E.—Ten grams of pure marble are dissolved in hydrochloric acid. Calculate what bulk of gas measured at 0°C and 760 mm. would be given off.

119. 1885. E.—If 180 grams of water be decomposed into its constituent gases, what bulk at the standard temperature and pressure will they occupy?

120. 1886. E.—Ten grams of hydrochloric acid (HCl) act on zinc, and the same weight acts on calcium carbonate. What bulk of gas, measured at the normal temperature and pressure, is produced in each case?

121. 1886. E.—Hydrogen is passed over red hot copper oxide (CuO), how much metallic copper is produced in forming 9 grams of water, and what is the volume of hydrogen at normal temperature and pressure which has been used?

122. 1886. E.—If air contains 21 per cent. by volume of oxygen, how many litres of it at standard temperature and pressure are required to burn completely 18 grams of carbon, and what would be the volume of the product formed? Weight of 11·2 litres of O = 16 grams.

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123. 1870. A.—How much hydrogen by weight and by volume (in litres) is required to reduce 25 grams of ferric oxide (Fe_2O_3) to metallic iron?

124. 1876. A.—How much sulphuric acid is required to decompose 500 grams of sodic carbonate, and what will be the volume of liberated carbonic anhydride?

125. 1883. A.—What volume of aqueous hydrochloric acid containing 36·5 grams HCl per litre, will be required to neutralize 224·5 grams of $Na_2CO_3 + 10H_2O$?

126. If 50 grams of chromium trioxide are heated, what will be the volume of the gas given off, measured at 0°C and 760 mm. pressure $2CrO_3 = Cr_2O_3 + 3O$?

127. What volume of oxygen measured at N.T.P. will be given off by heating 3·98 grams of potassic bichromate with sulphuric acid?

$$2K_2Cr_2O_7 + 10H_2SO_4 = 4KHSO_4 + 2Cr_2(SO_4)_3 + 8H_2O + 3O_2.$$

128. What volume of chlorine at N.T.P. is required to convert 40 grams of alumina into aluminium chloride?

$$Al_2O_3 + 3Cl_2 + 3C = 3CO + Al_2Cl_6.$$

129. How much sodium can be obtained from 73 kilograms of sodic carbonate, and what volume of carbon monoxide will be given off?

130. If 35 grams of pure iron are dissolved in hydrochloric acid, what volume of gas will be given off, measured at N.T.P.?

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IX.—CALCULATION OF EMPIRICAL FORMULÆ.

To find the Empirical Formula of a body from its percentage composition.

RULE:—

(a) Divide the percentage proportion of each element by the atomic weight of that element.

(b) Divide each quotient obtained in (a) by the lowest number.

(c) Convert the new quotients into the simple relation in whole numbers.

These numbers then represent the proportionate number of atoms of each element in a molecule of the compound.

EXAMPLE.—An analysis of a salt gave the following percentage numbers; what is its empirical formula?

Sulphur - - - -	22·53
Sodium - - - -	32·39
Oxygen - - - -	45·08
	100·00

$$S = \frac{22{\cdot}53}{32} = {\cdot}704 = 1({\cdot}704) = S.$$

$$Na = \frac{32{\cdot}39}{23} = 1{\cdot}408 = 2(704) = Na_2.$$

$$O = \frac{45{\cdot}08}{16} = 2{\cdot}817 = 4({\cdot}704) = O_4.$$

∴ Empirical formula is Na_2SO_4.

QUESTIONS VIII.

131. 1868. E.—A compound of iron and oxygen contains 72·4 per cent. of iron and 27·6 per cent. of oxygen. What is its formula?

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132. 1876. E.—What is the chemical formula of a body having the following percentage composition?

Sulphur - - - -	32·65
Oxygen - - - -	65·31
Hydrogen - - -	2.04
	100·00

133. 1884. E.—An experiment made to ascertain the composition of water by weight gave the following results:—

Weight of tube and copper oxide before experiment - 32·325.
" " " after " - 24·333.
Weight of calcium chloride tube before " - 40·462.
" " " after " - 49·494.

Find the simplest proportion in which the constituent elements have combined.

134. 1868. A.—An analysis of a salt gave the following numbers. What is its empirical formula?

Sulphur - - - -	22·53
Sodium - - - -	32·39
Oxygen - - - -	45·08
	100·00

135. 1869. A.—An analysis of a mineral gave the following numbers. What is its empirical formula?

Silicon - - - -	26·27
Calcium - - - -	18·43
Magnesium - - -	11·06
Oxygen - - - -	44·24
	100·00

136. 1882. A.—A salt on analysis gives the following per-centage numbers, N = 9·09, O = 20·77, Ag = 70·13. Calculate the simplest formula for this body. (N = 14, O = 16, Ag = 108).

137. 1886. A.—Calculate the formula for a body which has the following percentage composition:—oxygen, 38·1; hydrogen, 0·8; phosphorus, 24·6; sodium, 36·5.

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138. What is the empirical formula of a substance having the following percentage composition?

Copper	34·46.
Iron	30·59.
Sulphur	34·95.

139. An analysis of a salt gave the following numbers:—

Potassium	38·68.
Nitrogen	13·89.
Oxygen	47·43.

What is its empirical formula?

140. Calculate the formula for a body with the following percentage composition:—Magnesium 21·65, phosphorus 27·92, oxygen 50·43.

141. What is the formula of a body with the following percentage composition:—manganese 71·69, oxygen 28·31?

142. Calculate the formula of a body with the following percentage composition:—barium 58·80, sulphur 13·75, oxygen 27·45.

143. What is the empirical formula for a body containing 72·41 per cent. of iron, and 27·59 per cent. of oxygen?

144. A compound of hydrogen and nitrogen was found to possess the following percentage composition. Calculate the formula,

Nitrogen	82·353
Hydrogen	17.647

From the following percentage compositions deduce the formulæ:—

145.

Carbon	20·00
Oxygen	26·67
Sulphur	53·33
	100·00

146.

Zinc	22·70
Sulphur	11·15
Oxygen	22·28
Water	43·87
	100·00

147.

Aluminium	16
Sulphur	28
Oxygen	56
	100

148.

Sodium	32·77
Aluminium	13·03
Fluorine	54·20
	100·00

For method of determining molecular formula see page 83.

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X.—TEMPERATURE AND THERMOMETRIC SCALES.

1. **The Temperature of a body** *is its thermal state considered with reference to its power of communicating heat to other bodies* (Maxwell).

When the power a body possesses of transferring heat decreases, the temperature falls, and, when it increases, the temperature rises.

2. **Temperature is usually measured** by the changes in volume brought about by heat in certain substances, such as air, alcohol, and mercury. Instruments used for estimating the temperatures of bodies are called **Thermometers.**

The volume assumed by a thermometric substance, surrounded by melting ice at normal atmospheric pressure, is always the same, and also when placed in the steam escaping from water boiling at N.T.P., the volume is always the same.

The two points (*a*) that at which ice melts, and (*b*) that at which water boils, are therefore the fixed points of the thermometric scale. The space between these fixed points may be divided into any number of equal parts called degrees, and similar graduations may be continued above the boiling and below the freezing points.

3. We have reason for supposing, *see page* 60 that **−273°C** is the lowest possible temperature; hence it is called the **Absolute Zero.**

Any temperature as registered by the centigrade scale may be converted into the absolute scale by adding 273 to it.

Thus— 15°C is (15+273) = 285°C on the absolute scale.
− 22°C is (−22+273) = 251°C ,, ,,

4. **The scales found in Thermometers** in general use are :—

Thermometer.	Freezing point.	Boiling point.	Division of intervals.
Centigrade (C) - -	0°C	100°C	100°C.
Fahrenheit (F) - -	32°F	212°F	180°F.
Reaumur (R) - - -	0°R	80°R	80°R.

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Now since the actual difference between the fixed points is the same in each case, it follows that :—

$$100°C \text{ scale} = 180°F \text{ scale} = 80°R \text{ scale.}$$
$$\therefore \quad 5°C \;,, = 9°F \;,, = 4°R \;,,$$

and again, since the freezing point of F scale is 32°F

$$\frac{C}{100} = \frac{F - 32}{212 - 32} = \frac{R}{80}.$$
$$\therefore \frac{C}{100} = \frac{F - 32}{180} = \frac{R}{80}.$$
$$\therefore \frac{C}{5} = \frac{F - 32}{9} = \frac{R}{4}.$$

EXAMPLE 1.—What reading on C scale corresponds to 212°F?

$$\text{Since } \frac{C}{5} = \frac{F - 32}{9}.$$
$$\text{and } F = 212.$$
$$\therefore \frac{C}{5} = \frac{212 - 32}{9}.$$
$$\therefore 9C = 5 \times 180.$$
$$C = \frac{900}{9}.$$
$$C = 100.$$

The reading of 212°F is 100°C.

EXAMPLE 2.—What reading on C scale corresponds to 25·5°R?

$$\text{Since } \frac{C}{5} = \frac{R}{4}.$$
$$\text{and } R = 25{\cdot}5.$$
$$\therefore \frac{C}{5} = \frac{25{\cdot}5}{4}.$$
$$\therefore 4C = 127{\cdot}5.$$
$$C = 31{\cdot}875.$$

The reading of 25·5°R is 31·875°C.

EXAMPLE 3.—What reading on the Fahrenheit scale corresponds to 60°C?

$$\text{Since } \frac{C}{5} = \frac{F - 32}{9}$$
$$\text{and } C = 60$$
$$\frac{60}{5} = \frac{F - 32}{9}$$
$$540 = 5F - 160$$
$$5F = 700$$
$$F = 140$$

The reading of 60°C is 140°F.

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Example 4.—What reading on the Fahrenheit scale corresponds to 80°R?

$$\text{Since } \frac{F-32}{9} = \frac{R}{4}.$$

$$\text{and } R = 80$$

$$\frac{F-32}{9} = \frac{80}{4}$$

$$4F - 128 = 720$$

$$4F = 848$$

$$F = 212$$ *The reading of 80°R is 212°F.*

Example 5.—What reading on the R scale corresponds to 15°F?

$$\text{Since } \frac{F-32}{9} = \frac{R}{4}$$

$$\text{and } F = 15$$

$$\frac{15-32}{9} = \frac{R}{4}$$

$$60 - 128 = 9R$$

$$9R = -68$$

$$R = -7{\cdot}5°$$

The reading of 15°F is −7·5°R, i.e. 7·5° below freezing point.

Example 6.—Express 100°C in Reaumur's scale.

$$\text{Since } \frac{R}{4} = \frac{C}{5}$$

$$\text{and } C = 100.$$

$$\frac{R}{4} = \frac{100}{5}$$

$$5R = 400.$$

$$R = 80.$$ *The reading of 100°C is 80°R.*

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QUESTIONS IX.

149. Express the following in degrees Centigrade :—
30°F ; 80°R ; −12°R ; 15°R ; 210°F.
20°F ; −13°F ; 0°F ; 22°R ; 235°F.

150. Express the following in degrees Fahrenheit :—
12°C ; 14°R ; 180°C ; −25°C ; 0°C ; —12°R ; 32°C.

151. Express the following in degrees Reaumur :—
64°F ; 25°F ; 0°F ; 32°F ; 250°C ; −10°C.

152. Sulphuric acid boils at 640°F, ether at 94°F ; what are the corresponding points on the Centigrade scale ?

153. Chloroform boils at 62°C, and carbonic acid at −78°C ; what are the corresponding points on the Fahrenheit scale ?

154. Mercury solidifies at −40°C ; what is the corresponding point on the Fahrenheit scale ?

155. Sodium melts at 95·6°C, and potassium at 62·5°C ; what are the corresponding points on the Fahrenheit scale ?

156. Cast-iron melts at 2822°F, and tin at 455°F. Calculate these temperatures in °C.

157. Convert 15°F into R scale.

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XI.—EFFECT OF TEMPERATURE ON THE VOLUME OF A GAS.

1. The Law of Gay-Lussac.—When any Gas or mixture of gases is heated its volume increases.

The ratio which the increased volume bears to the original volume has been found experimentally to be $\frac{1}{273}$ of the volume of the gas at 0°C for every increase in temperature of one degree centigrade. For this reason the fraction $\frac{1}{273}$ or ·00367 is called the coefficient of expansion of gases.

All perfect gases when heated expand $\frac{1}{273}$ of their volume measured at 0°C for each rise of 1°C.

2. The Law of Charles.

The pressure remaining the same, the volume of any gas or mixture of gases varies directly as the **absolute temperature**.

The volume of a gas also decreases $\frac{1}{273}$ of its volume at 0°C for every degree centigrade from 0° downwards. If the temperature were reduced to − 273°C all gases would probably liquify, but this temperature has not been reached. For this reason − 273°C is called the absolute zero of temperature. To find the absolute temperature of a body, add 273 to the number of degrees as registered by the centigrade scale.

3. When Solids and Liquids are heated they usually increase in volume, and they decrease in volume when they part with heat.

The ratio of the increase and decrease varies with different bodies and is usually so small that it is generally neglected in simple chemical problems. In works on physics, tables may be found giving the relative rates of expansion for all the more important solids and liquids.

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The cubical expansion of a body is the increase of bulk which the substance undergoes on being heated. The fraction by which a body increases in volume for an increase in temperature of 1°C is called its **coefficient of expansion.** A short table for some important bodies will be found on page 12, but it must be remembered that these numbers are only true within certain limits of temperature, for solids and liquids do not expand like gases with perfect regularity at all temperatures. Since the coefficient of expansion of a solid or liquid body is the fraction by which the material will increase in volume for a rise of temperature of 1°C, it is evident if x stands for this coefficient, that—

1cc of a body at 0°C will become at 1°C $(1 + x)$
" " " " 2°C $(1 + 2x)$
" " " " 3°C $(1 + 3x)$
" " " " n°C $(1 + nx)$
and 2cc " " " 1°C $(2 + 2x)$
" " " " 2 $(2 + 4x)$
and Vcc at 0°C will become at 1°C $(V + Vx)$
" " " t°C $(V + Vxt)$

therefore, if V = volume at 0°C
V' = volume at t°C
t = temperature
$V' = V(1 + xt)$.

EXAMPLE 1.—The coefficient of mercury being taken as ·0001790. What volume will 100 cc of mercury measured at 0°C measure when its temperature is raised to 15°C?

Since $V' = V(1 + xt)$
then $V' = 100(1 + \cdot000179 \times 15)$
$V' = 100{\cdot}02685$ litres.

For other examples, *see* questions 402, 403, 404, and 405, page 111.

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4. When 1 volume of a gas at 0°C is raised in temperature to 1°C it occupies $(1 + \frac{1}{273})$ volumes.

Again, 273 volumes of a gas at 0°C raised in temperature to 1°C will occupy (273 + $\frac{1}{273}$ of 273) vols., or (273 + 1) vols. = 274 vols.

273	vols.	of	gas	at	0°C	raised to	1°C	= 273 + 1	vols.
273	,,	,,	,,	,,			2°C	= 273 + 2	,,
273	,,	,,	,,	,,			3°C	= 273 + 3	,,
273	,,	,,	,,	,,			4°C	= 273 + 4	,,
273	,,	,,	,,	,,			t°C	= 273 + t	,,
273	,,	,,	,,	,,			T°C	= 273 + T	,,

Hence $(273 + t)$ vols. of a gas at t°C raised to T°C = $(273 + T)$ vols.

$\therefore$ 1 vol. ,, ,, ,, ,, = $\frac{273 + T}{273 + t}$,,

$\therefore$ v vols. ,, ,, ,, ,, = $\frac{v\,(273 + T)}{(273 + t)}$,,

If V stands for the new volume of the gas after change in temperature

v ,, ,, original ,, ,, before ,, ,,
T ,, ,, new temperature.
t ,, ,, original.

Then from above

$$V = \frac{v(273 + T)}{273 + t}.$$

$$i.e.:-V = \frac{v \times \text{absolute temperature of new volume}}{\text{absolute temperature of original volume}}.$$

EXAMPLE 1.—Find the volume at 50°C of 125 cc. of hydrogen measured at 0°C, the pressure remaining the same.

$$V = \frac{v(273 + T)}{273 + t}.$$

v = 125 cc.
T = 50°C.
t = 0°C.

$$\therefore V = \frac{125\,(273 \times 50)}{273 + 0} = \frac{125 + 323}{273} = 147{\cdot}8 \text{ cc.}$$

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EXAMPLE 2.—If the temperature of 500 cc. of oxygen measured at 25°C is reduced to − 15°C, what is the new volume occupied?

$$V = \frac{v\,(273 + T)}{273 + t}.$$

$v = 500$ cc.
$T = -15$°C.
$t = 25$°C.

$$V = \frac{500\,(273 - 15)}{273 + 25} = \frac{500 \times 258}{298} = 432{\cdot}8 \text{ cc.}$$

EXAMPLE 3.—If 10 litres of a gas measured at − 12°C are heated to 15°C, what space will the gas then occupy?

$$V = \frac{v(273 + T)}{273 + t}.$$

$v = 10$ litres.
$T = 15$°C.
$t = -12$°C.

$$V = \frac{10\,(273 + 15)}{273 - 12} = \frac{10 \times 288}{261} = 11{\cdot}03 \text{ litres.}$$

5. In some cases it will be found more convenient to use the decimal equivalent instead of the vulgar fraction $\frac{1}{273}$.

Thus 1 volume of a gas at 0°C becomes:—

$1 + (\cdot00367 \times 1)$ vols. at 1°C.
$1 + (\cdot00367 \times 2)$,, 2°C.
$1 + (\cdot00367 \times 3)$,, 3°C.
$1 + (\cdot00367 \times t)$,, t°C.

6. From the above we see that where—

Vt = the vol. of the gas at t.
Vo = ,, ,, ,, 0°C.
t = the temperature on the C scale.
p = the pressure.
$Vt = Vo(1 + \cdot00367t)$ [p. constant].

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XII.—EFFECT OF PRESSURE ON THE VOLUME OF A GAS.

1. **The Law of Boyle.**—The volume of every perfect gas is inversely proportional to the pressure to which it is subjected.

The volume of a mass of gas multiplied by the pressure at one time is equal to the volume of the same mass of gas multiplied by the pressure at any other time.

Let $V\,v$ = new and original volumes of a given mass of a gas.
And $P\,p$ = new and original pressures to which the given mass of gas is subjected.

$$V\,P = v\,p \;\therefore\; V = \frac{v\,p}{P}$$

EXAMPLE 1.—If the pressure on 10 litres of gas be increased from 760 mm. to 1520 mm.; what will be the new volume?

$v = 10$ litres. $\quad p = 760$ mm. $\quad P = 1520$ mm.

$$V = \frac{v\,p}{P} = \frac{10 \times 760}{1520} = 5 \;\therefore \text{ new vol. is 5 litres.}$$

EXAMPLE 2.—If the pressure on 20 litres of air at 380 mm. be increased to 400 mm.; what will be the new volume?

$v = 20$ litres. $\quad p = 380$ mm. $\quad P = 400$ mm.

$$V = \frac{v\,p}{P} = \frac{20 \times 380}{400} = 19 \;\therefore \text{ new vol. is 19 litres.}$$

2. If the **pressure** to which a gas is subjected is **changed as well as its temperature,** then the two formulæ given above may be combined thus:—

$$V = \frac{v(273 + T)}{273 + t} \times \frac{p}{P}\text{; or } V = Vo(1 + \cdot00367t) \times \frac{p}{P}$$

3. From this formula we may find the volume which any gas should occupy at atmospheric pressure, and at a temperature of 0°C even if the substance in question cannot exist in the gaseous state at that pressure and temperature.

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4. Since the pressure of any gas is in direct ratio to the height of the barometric column which it sustains, and the normal atmospheric pressure is assumed to be equal to that of a column of mercury 760 mm. in height, we have, where H is measured in millimetres, a convenient modification of the above formulæ.

$$Vo = \frac{H}{760 \text{ mm.}} \quad \frac{Vt}{1 + \cdot00367t}$$

EXAMPLE 3.—If 500 cc. of air at 0°C, and 760 mm. is raised in temperature to 25°C the pressure falling to 725 mm.; what will be the new volume occupied?

$$V = \frac{v(273 + T)}{273 + t} \times \frac{p}{P} = \frac{500\ (273 + 25)}{273 + 0} \times \frac{760}{725}.$$

$$= \frac{500 \times 298 \times 760}{273 \times 725} = 572{\cdot}1 \text{ cc.} = \text{new vol.}$$

QUESTIONS X.

158. 1868. A.—A gas measures 117·9 cubic inches at 9·9°C and 700·9 millimetres mercurial pressure. Required its volume at 0°C and 1 metre mercurial pressure.

159. 1869. A.—I measure 100 cubic centimetres of dry nitrogen at 10°C and 650 millimetres mercurial pressure. What will be its volume at 0°C and 760 millimetres pressure, and how much will it weigh in grams?

160. 1872. A.—If a gas measures 25 cubic centimetres at 14°C under a pressure of 350 millimetres of mercury, what volume will it occupy at 0°C under a pressure of 760 millimetres of mercury?

161. 1873. A.—At what rate do gases expand by heat? 200 cubic centimetres of hydrogen are measured at 60° Fahr. and 29 inches barometrical pressure; what would the gas measure at 0°C and 760 mm. mercurial pressure?

162. 1879. A.—How many milligrams of water are formed when an electric spark is passed through a mixture of 400 cbc. of hydrogen and 150 cbc. of oxygen, measured at 10°C and under a pressure of 740 mm.?

163. 1881. A.—If 22·4 litres of hydrogen at 0°C and 760 mm. pressure weigh two grams, what will be the weight of an equal bulk of ammonia at 100°C and 380 mm. pressure?

164. At a constant temperature a mass of air occupies 25 cubic feet under a pressure of 10 lbs.; what space will it occupy under a pressure of 24 lbs.?

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165. A mass of gas occupies 510 cubic feet at 27°C; what space will it occupy at 67°C under the same pressure?

166. If 1,365 cubic feet of gas under a constant pressure are heated from 0°C to 50°C, what will be the volume of the gas at the last temperature?

167. A mass of gas occupies 864 cc. at 15°C, what space will it occupy at 40°C at the same pressure?

168. What volume of gas measured at 18°F. and 560 mm. pressure is obtained from 350 milligrams of potassic chlorate?

169. How many cubic centimetres of hydrogen can I obtain from 75 litres of steam, the hydrogen is measured at 155°C and 758 mm. pressure?

170. A quantity of air which occupies 26 cc. at a temperature of 59°F and under a pressure of 29 inches of mercury, is raised in temperature to 68°F, and the pressure is increased to 50 inches of mercury; what is the new volume of gas?

171. What volume of gas measured at 28°C and 748 mm. pressure can be obtained from 5 grams of Formic acid when heated with sulphuric?

172. A gas has its temperature raised to 50°C from 15°C; at 50°C it measures 15 litres; what volume did it occupy at 15°C?

173. If 120 cc. of a gas measured at 35°C, and under a pressure of 30 inches is raised in temperature to 46°C, whilst the pressure is reduced to 25 inches; find its volume.

174. How much phosphorus is required to remove all the oxygen from 100 litres of air at 15°C, and 740 mm.?

175. I require 38 litres of carbon monoxide at 18°C and 672 mm.; how much dry oxalic acid must be used?

176. What volume would 1640 cc. of phosphine gas (PH_3) measured at 15°C and 297 mm., occupy at 10°C and 302 mm.?

177. What volume of ammonia at 15°C and 740 mm. could be obtained from 107 grams of ammonic chloride?

178. What is the volume of the mixed gases measured at 15°C and under a pressure of 725 mm. yielded by the action of sulphuric acid on 15 grams of carbon?

179. What volume of oxygen in cubic centimetres measured at 18°F and 560 mm. can be obtained by heating 175 grams of potassic chlorate?

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180. 1885. A.—What weight in kilograms of zinc and sulphuric acid will yield hydrogen enough to fill a balloon of 350 cubic metres capacity, at 15°C, and 735 mm. pressure; and what fraction of the gas will escape when the balloon has reached an elevation where the barometer stands at 335 mm. pressure, supposing the temperature constant?

181. 1874. A.—What volume of carbonic anhydride measured at 745 mm. and 15°C can be obtained from 150 grams of marble containing 3 per cent. of silica?

182. 1875. A.—What volume of hydrogen, measured at 12°C and 750 mm., is disengaged when 100 grams of zinc dissolve in dilute sulphuric acid?

183. 1877. A.—How many litres of oxygen at 750 mm. and 15°C can be obtained by heating 261 grams of manganese dioxide (black oxide of manganese) Mn = 55?

184. 1880. A.—All the gas obtained by treating 3 grams of calc-spar with acid is heated to 210°C and then cooled to 15°C; state the volume in cubic centimetres it will occupy in each case, the barometer remaining at 760 mm.

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XIII.—DIFFUSION OF GASES.

1. The rate at which a gas diffuses varies with its density; the lighter a gas is, the more readily does it diffuse. The exact rule of diffusion is expressed by **Graham's Law.** "*Gases diffuse into one another inversely as the square roots of their densities.*"

Thus, the densities of hydrogen and oxygen are 1 and 16, the inverse of these numbers are 1 and $\frac{1}{16}$, and the square roots of these inversions 1 and $\frac{1}{4}$; therefore, while 1 volume of hydrogen diffuses, $\frac{1}{4}$ of that volume, of oxygen will diffuse, under the same conditions, *i.e.* the diffusing power of hydrogen is 4 times that of oxygen.

2. To re-state the law then—the volumes of two gases which diffuse in equal times under the same conditions, are inversely proportional to the square roots of their densities.

It follows from this, that when two gases of different densities diffuse through an apparatus for equal times, under similar circumstances, the volume of the one gas diffused multiplied by the square root of its density equals the volume of the other gas diffused multiplied by the square root of its density.

Volume × square root of density = vol. × square root of density.

Let V and v = volumes of two gases.

,, D and d = densities of two gases.

Then $V\sqrt{D} = v\sqrt{d}$.

EXAMPLE 1.—Five litres of hydrogen diffuse through an apparatus in a certain time, what quantity of oxygen will diffuse through it in the same time?

D of oxygen = 16 and d of hydrogen = 1.

$$V\sqrt{D} = v\sqrt{d}.$$

$$V\sqrt{16} = 5\sqrt{1.}$$

$$V = 5.\frac{\sqrt{1}}{\sqrt{16}}$$

$$V = \frac{5 \times 1}{4}$$

$$V = 1{\cdot}25 \text{ litres of Oxygen.}$$

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3. The following table will show how nearly the rate of diffusion of common gases as calculated agrees with the results of experiments. The velocities of diffusion in each case are referred to air as the standard of both density and velocity of diffusion :—

Name of Gas.	Density.	Square Root of Density.	$\frac{1}{\sqrt{\text{Density.}}}$	Velocity of Diffusion.
Air	1	1	1	1
Hydrogen	·0692	·263	3·779	3·830
Oxygen	1·105	1·051	·951	·948
Nitrogen	·971	·985	·1014	1·014
Marsh Gas...	·559	·747	1·337	1·344
Carbon Dioxide	1·529	1·236	·808	·812

It will be observed from the above table that the velocity of diffusion of hydrogen is four times that of oxygen, while the square roots of their relative densities are in the ratios of one to four.

4. *The law stated on page 68 as shown by the tabulated experimental results given above is true of compound gases.*

EXAMPLE 2.—20 litres of oxygen diffuse through an apparatus in a certain time, what volume of ammonia gas will diffuse through it in the same time and under similar conditions ?

d of O = 16; D of NH_3 = 8·5.

$$V\sqrt{8{\cdot}5} = 20\sqrt{16.}$$

$$V = 20\frac{\sqrt{16}}{\sqrt{8{\cdot}5}}.$$

$$V = \frac{20 \times 4}{2{\cdot}9}.$$

V = 27·5 litres of NH_3.

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EXAMPLE 3.—1·25 litres of oxygen diffuse through an apparatus in the same time as 5 litres of hydrogen when under similar conditions, what is the density of the oxygen?

d of hydrogen = 1.

$$\sqrt{D} = 5\sqrt{1.}$$

$$\sqrt{D} = \frac{5}{1{\cdot}25}.$$

$$\sqrt{D} = 4.$$

$$D = 16.$$

Therefore density of oxygen = 16.

QUESTIONS XI.

185. How many vols. of hydrogen will diffuse out of vessel in the same time that 2 vols. of chlorine take (Cl = 36)?

186. If 30 vols. of oxygen diffuse out of a vessel in 10 minutes, how long will 20 vols. of chlorine take to diffuse out of the same vessel? (Cl = 36).

187. If 20 vols. of hydrogen diffuse out of a vessel in 10 minutes, how many volumes of chlorine will diffuse out of the same vessel in 30 minutes?

188. What are the laws of diffusion of gases? If 20 volumes of hydrogen take 10 minutes to diffuse out of a vessel, how long will 50 volumes of oxygen take to diffuse under like conditions?

189. What volume of chlorine will diffuse under the same circumstances as 10 litres of nitrogen?

190. 2·5 litres of oxygen diffuse through an apparatus in the same time as 10 litres of hydrogen, when placed under similar conditions, deduce from this the density of oxygen.

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XIV.—SPECIFIC, ATOMIC, AND MOLECULAR HEAT.

1. **The Specific Heat** or capacity of a substance for heat is the ratio of the quantity of heat required to raise any weight of that substance 1°C to the quantity of heat required to raise an equal weight of water from 0°C to 1°C.

The unit of comparison is 1 gram of water at 0°C. Thus, *we may define the specific heat of a substance as the quantity of heat required to raise 1 gram of the substance 1° C as compared with the quantity of heat required to raise 1 gram of water from 0° C to 1° C.*

2. It has been found that the capacities for heat (specific heats) of the various elements in the solid state differ much from one another.

If, instead of comparing together the quantities of heat required to raise equal weights of the elements 1°C, we compare together the amounts of heat necessary to increase similarly the temperature of quantities of the elements, which stand to each other as their atomic weights, we find that all these quantities of heat are nearly equal to one another.

3. The product of the specific heat of an elementary solid into its atomic weight is, with certain exceptions, a constant quantity (about 6·4).

This law, which is named after two French chemists as **Dulong and Petits' Law,** may be exactly stated thus:—

"The specific heat of an element in the solid condition multiplied by its atomic weight, is called the **atomic heat of the element.**" This simply means that the amount of heat required to raise atomic weights of different solid elements is a constant quantity.

Specific heat × *atomic weight* = *atomic heat.*

It follows from this, that, inasmuch as the atomic heat is a constant quantity, by carefully ascertaining experimentally the specific heat of an element in the solid state, we have a means of calculating the atomic

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weight. Hence, if 6·4 be divided by the specific heat of an element, a number approximately near to its atomic weight is obtained.

$$\text{Atomic weight} = \frac{\text{atomic heat}}{\text{specific heat}}.$$

EXAMPLE.—The specific heat of platinum is ·0324; find its atomic weight.

$$\frac{6{\cdot}4}{{\cdot}0324} = \text{atomic Wt. of Pt.} = 197.$$

Element.	Symbol.	Specific Heat × Atomic Weight = Atomic Heat.				
Lithium	Li	·9410	×	7·0	=	6·6
Lead	Pb	·0315	×	206·4	=	6·5
Platinum	Pt	·0324	×	196·7	=	6·4
Iron	Fe	·1120	×	56·0	=	6·3
Copper	Cu	·0950	×	63·4	=	6·0
Silver	Ag	·0570	×	107·66	=	6·1
Tin	Tu	·0548	×	117·8	=	6·5

4. **The Molecular Heat** of a compound is the sum of the atomic heats of the combined atoms, and it is found in the same manner as the atomic heat of an element by multiplying together the specific heat and the molecular weight.

For example, potassic chloride has the specific heat ·173, and molecular weight 74·5.

·173 × 74·5 = 12·8, the molecular heat of KCl.

Experiments have shown that chlorides of the type M′Cl have average molecular heats of 12·8, and those of the type M″Cl_2 about 18·5.

Since it has been shown by experiment in numerous cases that the molecular heat of a compound is equal to the sum of the atomic heats of the constituent elements in the solid form, we have a means of estimating approximately the specific heats of solid oxygen, hydrogen, and nitrogen, which cannot be determined by direct experiment.

Thus the molecular heats of—

KCl = 12·8.
$KClO_3$ = 24·8.
O_3 by difference 12.

And the atomic heat of oxygen is therefore $\frac{12}{3} = 4$.

The molecular heat of KNO_3 = 24·1
K = 6·4
O_3 = 12

By difference 24·1 − 18·4 = 5·7 atomic heat of N.

The molecular heat of H_2O (ice) = 9
O = 4

$9 - 4 = 5$ and $\frac{5}{2} = 2{\cdot}5$.

Atomic heat of solid hydrogen is approximately 2·5.

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Compound.	Formulæ.	Specific Heat.	×	Molecular Weight.	=	Molecular Heat.
Sodic Chloride	NaCl	·219	×	58·5	=	2 × 6·4
Potassic Bromide	KBr	·107	×	119·1	=	2 × 6·4
Stannous Chloride	$SnCl_2$	·102	×	189	=	3 × 6·4
Lead Iodide	PbI_2	·0427	×	459·6	=	3 × 6·4

5. The **Atomic Heats of some of the elements are abnormal**; thus those of *Boron*, *Carbon*, and *Silicon*, determine at low temperatures, are, respectively, 3, 1·8, and 4·8; but it has been found that the higher the temperature, the more nearly the atomic heat in each case approaches the number 6·4; but it should be recognised, that while the atomic weight of an element is an unvarying ratio, it is found that the specific heat of an element varies, in some cases, considerably, according to its physical condition in all cases it is greatest for the solid and least for the gaseous form, and it invariably increases with a rise of temperature.

6. **The atomic weight of a body** is in most cases very difficult to determine and necessitates the performance of many complex experiments, and accurate observation involving generally much work; on the other hand, the specific heat of a body may be determined with ease and accuracy by a few simple experiments.

By the application of Dulong and Petit's Law, and a knowledge of the specific heat of a metal, we have an easy means of deciding in doubtful cases the atomic weight of the same.

For example, the metal indium combines with chlorine in the proportion of 57 : 35·5, and, therefore, the formula for chloride of indium may be written from this InCl or $InCl_2$ or $InCl_3$. In the first case the atomic weight of indium would be 57, in the second 114, and in the third 171; in each case the ratio of metal to chlorine would be the same. But when it is found that the specific heat of indium is ·057, we can only accept 114 as the atomic weight for (114 × ·057) = 6·5; this gives 6·5 as the atomic heat of the metal, whilst (57 × ·057) would give less than 6·5, and 171 × ·057 would give more than the constant of Dulong and Petit.

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6. The Specific Heats of Important Metallic Elements :—

Element.		Specific Heat.	Atomic Weight.	Atomic Heat.
Lithium	Li	·941	7	6·6
Sodium	Na	·293	23	6·7
Magnesium	Mg	·250	24	6·0
Aluminium	Al	·225	27	6·1
Potassium	K	·166	39	6·5
Iron	Fe	·114	56	6·3
Nickel	Ni	·108	586	6·3
Cobalt	Co	·107	59	6·3
Copper	Cu	·095	63	6·0
Zinc	Zm	·093	65	6·1
Arsenic	As	·082	75	6·1
Silver	Ag	·056	108	6·0
Cadmium	Cd	·055	112	6·1
Tin	Sn	·055	118	6·5
Platinum	Pt	·032	195	6·3
Gold	Au	·032	196	6·3
Mercury	Hg	·032	200	6·4
Lead	Pb	·031	206	6·4

QUESTIONS XII.

191. 1881. A.—The specific heat of iron is 0·1140, of lead ·0315, of potassium 0·1660. Explain the meaning of these numbers. Calculate the atomic heat of the metals.

192. The specific heat of sodium is ·2934, and 39·32 grams of sodium unite with bromine to form 176·08 grams of sodic bromide. Find the atomic weight of sodium.

193. The specific heat of cobalt is ·107. Calculate its atomic weight.

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XV.—LATENT HEAT AND THE LOWERING OF THE FREEZING POINT OF SOLUTIONS.

1. **The Latent Heat** of a body is the quantity of heat which must be communicated to a substance in a given state in order to convert a unit mass of it into another state without changing its temperature.

The **Latent Heat of Water is 79·25**, *i.e.*, the amount of heat which is necessary to convert 1 lb. of ice at 0°C into 1 lb. of water at 0°C is the same as would raise 79·25 lbs. of water from 0°C to 1°C, or 1 lb. of water from 0°C to 79·25°C.

The Latent Heat of Steam is 537, *i.e.*, the amount of heat required to change 1 lb. of water at 100°C into 1 lb. of steam at 100°C would raise 537 lbs. of water from 0°C to 1°C.

The heat rendered latent in changing a solid into a liquid is called the *latent heat of fusion.* That employed in turning a liquid into a gas is termed the *latent heat of vapourization.*

2. **Raoult's Law.** It has been discovered that when solids are dissolved in liquids which solidify at ascertainable temperatures, the freezing point is depressed according to the following law:— The molecular weight in grams of any substance dissolved in one hundred times the molecular weight in grams of any solvent lowers the freezing point of the latter 0·62°C.

Let L be the lowering of the freezing point produced by one gram of the substance under investigation, dissolved in 100 grams of the solvent.

M the molecular weight of the dissolved body.

T the lowering of the freezing point produced by the molecular weight in grams of the substance dissolved in 100 grams of the solvent.

$$\text{Then } L\,M = T\,; \text{ and } M = \frac{T}{L}$$

Again, if W be the weight of the solvent taken and w the weight of the dissolved body, and l the lowering of the freezing point, as found by experiment, then

$$L = l.\frac{W}{w \times 100}\,; \text{ and } M = \frac{T\,(w \times 100)}{Wl}$$

If M' represent the molecular weight of the solvent, then

$$T = M' \times 0{\cdot}62.$$

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XVI.—VAPOUR DENSITY AND MOLECULAR FORMULÆ.

1. The **Vapour density** of a body is the weight of a volume of the body in the gaseous state compared with the weight of an equal volume of hydrogen under like conditions of temperature and pressure.

2. There are two principal methods of determining the vapour density of a substance, namely, those of *Dumas* and *Gay-Lussac*, of which modified plans have been devised by *Hofmann* and *Victor Meyer*.

In the former we determine the weight of a certain volume of the vapour of a substance, and compare this with the weight of the same volume of hydrogen under the same conditions of temperature and pressure.

In the latter we ascertain the volume of a certain weight of the substance when converted into a vapour, and compare this weight with the calculated weight of the volume of hydrogen which is equal to the volume of the vapour produced.

3. **Dumas' Method.**—A glass globe of 250 or 350 cc. capacity, the neck of which is drawn to a fine point, is usually employed. This is carefully weighed and a sufficient quantity of the substance to be tested is introduced in a liquid state. The globe is then placed in an oil bath and the temperature raised to 30° or 40° above the boiling point of the liquid. The liquid within the globe now boils and a rapid stream of vapour escapes from the drawn out end, which has been left above the oil. At the moment that the rush of vapour ceases the glass point at which the vapour escaped is melted together with the blow-pipe flame, the temperature of the bath and the height of the barometer at the time are recorded. The globe is then removed from the bath, cleaned from adhering oil, and again weighed, the temperature and height of the barometer

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being once more recorded. The point of the globe is then broken off whilst immersed in mercury, the weight or volume of mercury which fills the globe is noted, and so the capacity of the globe is ascertained. The vapour density of a substance may be determined from the data thus obtained.

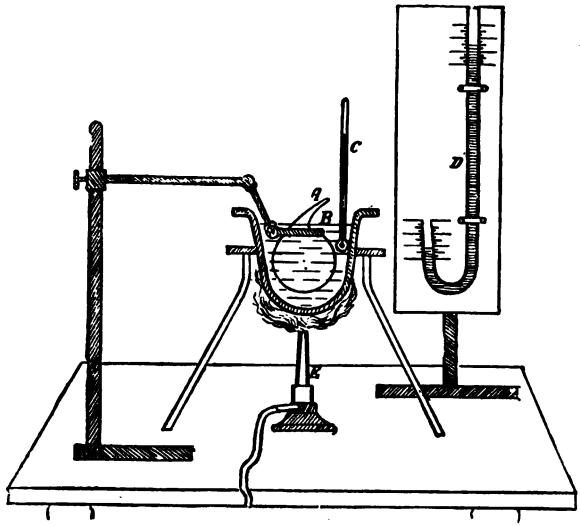

FIG. 2.—APPARATUS FOR DUMAS' METHOD OF DETERMINING VAPOUR DENSITY.

4. In this method we see that it is necessary to record

1. *The weight of the glass globe A filled with air.*
2. *The temperature of the air at the time of weighing.*
3. *The barometric pressure by D at the time of weighing A.*
4. *The temperature of the bath B at the time of sealing the globe A.*
5. *The barometric pressure at the time of sealing the globe.*
6. *The weight of the globe filled with the vapour of the substance taken.*
7. *The capacity of the glass globe.*

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5. EXAMPLE 1.—In an actual experiment the following facts were recorded by Dumas' method. You are required to calculate the vapour density of the body under investigation :—

Weight of glass globe filled with air - - -	22·8043 grams.
,, ,, ,, vapour of substance	22·9223 ,,
Temperature at time of weighing - - - -	15°C.
Barometer ,, ,, - - - -	750 mm.
Temperature of bath at time of sealing globe -	150°C.
Barometer ,, ,, ,, - -	755 mm.
Capacity of globe - - - - - - -	230 cc.

Neglecting the minor calculations for the expansion of the glass, etc., the vapour density may be obtained from the above data.

(*a*) In order to obtain the weight of the vacuous globe, that is, of the glass alone, we must subtract the weight of the air in it, at the time of weighing, from the total weight. But it is first necessary to find the volume the air would occupy at 0°C and 760 mm.

The globe contained 230 cc. of air at 15°C and 750 mm. and

230 cc. of air at 15°C and 750 mm.
become 215·15 ,, ,, 0°C ,, 760 mm.

$$\text{For } V = \frac{230\,(273 + 0)}{273 + 15} \times \frac{750}{760} = 215{\cdot}15 \text{ cc.}$$

And since 1000 cc. of air at 0°C and 760 mm. pressure weighs 1·293 grams.

1 cc. ,, ,, ,, ·001293 grams.
∴ 215·15 ,, ,, ,, (215·15 × ·001293) = ·2782 grams.

Hence, the weight of the vacuous globe is (22·8043 − 0·2783) = 22·5260 grams, and the weight of the vapour is (22·9223 — 22·5260) = ·3963 grams.

(*b*) We have next to find the weight of the same volume of hydrogen if measured under similar circumstances.

230 cc. of H at 150°C and 755 mm. will become
147·46 ,, ,, 0°C and 760 ,,

$$\text{For } V = \frac{230\,(273 + 0)}{273 + 150} \times \frac{755}{760} = 147{\cdot}46 \text{ cc.}$$

And since 1000 cc., *i.e.*,—
1 litre of H at 0°C and 760 mm. weighs ·0896 grams.
1 cc. ,, ,, ,, ·0000896 ,,
147·46 cc. ,, ,, ,, (147·46 × ·0000896) ·01321 grams.

(*c*) Hence, the vapour density of the body under investigation, compared with hydrogen, is $\frac{\cdot 3963}{\cdot 01321} = 30$ Ans.

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6. Victor Meyer's Method, of which there are several modifications, is a plan in which we ascertain the volume of the vapour produced from a given weight of a substance at a known temperature and pressure. The apparatus employed is shown in Fig. 3, where *A* is a glass tube blown into a large bulb at *B*, and with a thistle top at *C* provided with an indiarubber stopper. A delivery tube *D* passes into a small trough of water or mercury in *E*, in which a graduated tube *F*, filled with water or mercury is fixed. The bulb *B* and greater part of the tube *A* is surrounded by a larger tube *G*, in which is placed the liquid for heating *AB*. For all ordinary substances the following liquids are used, according to the vaporization point of the body under investigation.

For bodies that vaporize below 100° water is used.

For bodies that vaporize below 183° aniline is used.

For bodies that vaporize below 260° amyl benzoate is used.

Sulphuric acid, lead, and other bodies are also employed in the bath in order to secure the complete vaporization of the substance under investigation.

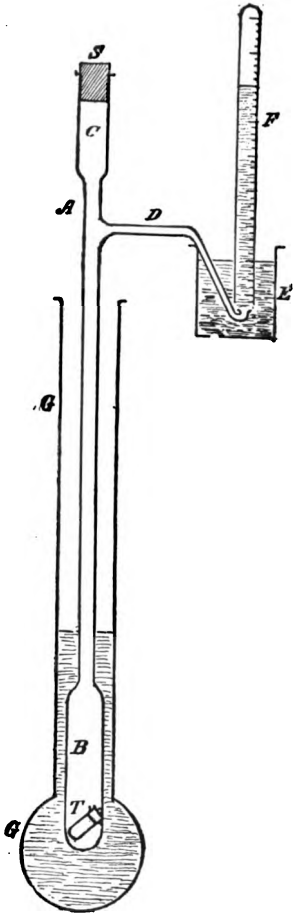

FIG. 3.—SKETCH OF APPARATUS EMPLOYED IN DETERMINING VAPOUR DENSITY BY VICTOR MEYER'S METHOD.

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6. METHOD—

1. Fit up the apparatus as shown in the sketch, and remove the graduated tube *F*, and heat the tube *G*, which serves as a bath, and observe that bubbles of air escape from the end of the delivery tube *D*.

2. Drop a piece of asbestos down the tube *A B*, which will serve as a cushion, and so prevent the breakage of the glass by concussion.

3. When air no longer escapes from *D*, fix up the graduated tube over the end of the delivery tube, as shown in the sketch.

4. Weigh out a small quantity of the substance of which the vapour density is to be ascertained into a small tube, *T*.

5. Remove the India-rubber stopper, and drop the tube into *A B*, so that it falls on to the asbestos cushion, and quickly replace the stopper.

6. The heat causes the body introduced to change into vapour, and the vapour produced will drive out its own bulk of air which will collect in the graduated tube, *F*.

7. When the flow of air from *A B* has ceased, lower *F* until the level of the surface of the water inside and outside is the same.

8. The volume is now read off the graduated tube, and the temperature of the water in contact with the air and the barometric pressure are recorded.

The vapour density is now found from the data obtained, and from a knowledge of the fact that the vapour density of a body is the weight of a given volume of a gas, compared with the weight of an equal volume of hydrogen under like condition of temperature and pressure. It is obvious that the mass of the gas formed from the substance is the same as the mass of the substance, and is therefore known.

Let this mass be *W*.

The mass of displaced air *w*.

The volume of the air = *v*

And it is also obvious that the volume of the gas produced from the body vaporized is equal to the volume of air which escapes into *F* through *D*.

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The specific gravity of the substance is, therefore $\frac{W}{w}$; and since the density of air is 14·42 times as great as that of hydrogen, we have the vapour density of the substance

$$D = \frac{W}{w} \times 14{\cdot}42$$

But the volume of the air reduced to standard temperature and pressure is to be found by the following formula.

$$V = v\frac{(273 + T)}{273 + t} \times \frac{p}{P}$$

Or

$$Vo = \frac{H}{760 \text{ mm.}} \quad \frac{Vt}{1 + {\cdot}00367t}$$

And since the mass of a cubic centimetre of air at 0°C and 760 millimetres pressure is $\frac{1}{773}$ of a gram.

$$w = \frac{Vo}{773} \text{ grams.}$$

In these formulæ v is the observed volume and V the volume reduced to 0°C, t the recorded temperature at time of working, and H the reading of the barometric column. The method would be complete, as described above, were the displaced air collected over mercury, but since it is more convenient for ordinary work to collect it over water a correction must be made for the water vapour which is mixed with the air collected in F. Since the air has passed through the water in small bubbles and has stood in contact with the water for some time, we may assume that the pressure of the water vapour is as great as possible under the existing conditions of temperature. A table of the maximum tension of water vapour at different temperature is given in the Appendix on page 120. Let h represent the pressure exerted by the water vapour, then the whole pressure in the tube F is the sum of the pressure of the air and the tension of the water vapour, *i.e.*, $(H - h)$, this must be substituted in the equation which now reads—

$$Vo = \frac{H - h}{760} \quad \frac{Vt}{1 + {\cdot}00367t}, \text{ and } w = \frac{Vo}{773}.$$

and, finally, $D = 14{\cdot}44\frac{W}{w} = \frac{14{\cdot}44\,W \times 760 \times 773(1 + 0{\cdot}0036t)}{(H - h)Vt}$.

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Since one litre of hydrogen gas at 0°C and 760 mm. barometric pressure weighs ·08958 grams, and one cubic centimetre weighs ·00008958 grams, then we may shortly write the formula—

$$D = \frac{W760\ (1 + 0{\cdot}00367t)}{Vo\ 0{\cdot}0008958(H - h)}.$$

D = the vapour density of body under investigation.
W = weight of body taken.
Vo = observed volume of displaced air in cc.
t = temperature of water in trough.
h = vapour tension of water at temperature of tube F (*See table page 120*).
H = Reduced height of barometric column at time of experiment.

The method is, therefore, to record the following data :—

1. *Weight of substance taken.*
2. *Temperature of trough at time air is collected.*
3. *Reduced barometric pressure at the same time.*
4. *Volume of air collected.*

EXAMPLE 1.—One of Victor Meyer's experiments gave the following results for chloroform heated in steam :—

Weight of substance taken - -	0·1008 gram.
Temperature of water - - - -	16·5°C
Barometric pressure reduced to 0°C and 760 mm.	707·5
Volume of air collected - - - -	22·0 cc.

From the formula—

$$D = \frac{W760(1 + 0{\cdot}00367t)}{Vo\ 0{\cdot}00008958\ (H - h)}$$

We have—

$$D = \frac{0{\cdot}1008 \times 760 \times (1 + 0{\cdot}00367 \times 16{\cdot}5)}{22{\cdot}0 \times 0{\cdot}0000895S \times (707{\cdot}5 - 13{\cdot}972)}.$$

D = 59·4 = The density of chloroform.

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7. Molecular Formulæ.—In Article IX, page 53, we have seen how to find the **empirical formula** of a body from the results of analytical calculations, but it is necessary to ascertain also the **molecular formula**, and this cannot be determined with equal ease and certainty; for the calculation of this we have to take into account the vapour density of the substance as calculated in Article XVI, page 76, and in the case of acids the nature of the salts formed.

Suppose, for example, that in a particular case the results of an ultimate analysis gave the following empirical formula for a body,

$$C_2H_6O,$$

from page 16 we see that this only expresses the *relative* proportion of atoms present in a molecule of the substance, and it is not the true or molecular formula of the body, for it does not inform us of the *absolute* number of atoms which go to make up a molecule of this body. It is obvious that the molecular formula of the body in question may therefore be written

$$C_{2n}H_{6n}O_n,$$

and, since the atomic weights of C, H and O are respectively 12, 1 and 16, its molecular weight according to this formula and Section 6, page 18, is 46_n.

Now, by Article XVI, page 76, we have seen how to determine the vapour density of a body, and we have learnt by Article II, page 30, that the molecular weight of a substance is twice its vapour density. Suppose, therefore, that the vapour density of this substance, as found by experiment, is 23·02.

The molecular weight must be $(23{\cdot}02 \times 2) = 46{\cdot}04$.

Whence we conclude that $n = 1$, and that the molecular formula is identical with the empirical formula, *i.e.*, C_2H_6O. Had the vapour density given as a result 46·04 we should have concluded that the molecular weight was 92·08, and in that case n would $= 2$ and the molecular formula would read $C_4H_{12}O_2$.

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QUESTIONS XIII.

194. (*a*) Calcula'e the vapour density of a substance from the following (hydrogen to be taken as standard) (Dumas' method).—

Weight of globe filled with air	17·3056 grams
,, ,, ,, vapour	17·3977 ,,
Temperature at time of weighing	15°C.
Temperature at time of sealing	150°C.
Capacity of globe	125 cc.
Barometer	755 mm.

194. (*b*) Calculate the temperature of carbon disulphide, heated in steam (Victor Meyer's method), from the following data :—

Weight of carbon disulphide	0·0495 grams.
Temperature of water	16·5°C.
Barometric pressure	717·8 mm.
Volume of air collected	16·4 cc.

195. (*a*) Calculate the vapour density of a substance from the following data :—

Weight of globe filled with air	23·449 grams.
,, ,, ,, vapour	23·720 ,,
Temperature of air at time of weighing	15·5°C.
Temperature of air at time of sealing	110·0°C.
Barometric pressure	760 mm.
Capacity of globe	178 cc.

195. (*b*) Calculate the vapour density of mercury (Victor Meyer's method), from the following :—

Weight of mercury taken	0·0905 grams.
Temperature of water	16·0°C.
Barometric pressure	715·8 mm.
Volume of air collected	11·5 cc.

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XVII.—ATOMIC WEIGHT CALCULATIONS.

196. 1868. E.—A normal or neutral salt of sulphuric acid and a dyad metal contains 21·05 per cent. of sulphur and 36·84 per cent. of metal. What is the atomic weight of the metal?

From question Sulphur + Metal.

$$21{\cdot}05 \quad + 36{\cdot}85 = 57{\cdot}89.$$

∴ Amount of Oxygen present in the normal salt = (100 − 57·89) = 42·11 per cent.

To find proportion of oxygen and sulphur.

$$\text{Oxygen} = \frac{42{\cdot}11}{16} = 2{\cdot}63 = 4(\cdot 65)$$

$$\text{Sulphur} = \frac{21{\cdot}05}{32} = \cdot 65.$$

∴ there is one of S. to 4 of O.

∴ formula stands thus, Metal SO_4 = M + 32 + (16)4.

and if x = atomic weight of unknown metal,

$(96+x)$ will = the molecular weight of salt.

If in 100 parts of the salt there are 36·84 of the metal.

∴ ,, 1 ,, ,, ·3684 ,,

∴ ,, $(96 + x)$,, ,, $\cdot 3684\,(96 + x)$,,

$$\cdot 3684\,(96 + x) = 35{\cdot}3664 + \cdot 3684x.$$

Now this is the number of parts in the whole sum of the atomic weights; and is, therefore, the atomic weight and is equal to x.

$$\therefore \quad x = 35{\cdot}3664 + \cdot 3684x.$$

i.e., $\cdot 6316x = 35{\cdot}3664.$

$$\therefore \quad x = 55.9 = \text{atomic weight of metal Ans.}$$

197. 1883. A.—By dissolving 0·442 grams of metallic cobalt in an acid, 177·4 cbc. of hydrogen at 10°C and 750 mm. acid, 177·4 cbc. of hydrogen at 10°C and 750 mm. pressure are obtained. The specific heat of the metal is 0·107. Calculate the atomic weight of cobalt.

Let us suppose x = atomic weight of cobalt.

By equation $Co + 2HCl = CoCl_2 + H_2$.

$$x \quad = \quad 2.$$

x grams of Cobalt produce 2 grams of H.

But 2 grams H occupy 22·32 litres at 0°C and 760 mm.

∴ x grams cobalt yield (see equation) 22·32 ,, of H ,, ,,

∴ 1 ,, ,, $\frac{22{\cdot}32}{x}$,, ,, ,, ,,

∴ ·442 ,, ,, $\frac{22{\cdot}32 \times \cdot 442}{x}$,, ,, ,,

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But by question ·442 grams Co produce 177·4 cbc. of H = ·1774 litres H at 10°C and 750 mm. pressure.

This quantity of H becomes at 0°C and 760 mm. pressure.

$$\frac{\cdot1774 \times 273 \times 750}{283 \times 760} = \cdot169 \text{ litres of hydrogen.}$$

$$\therefore \quad \frac{22{\cdot}32 \times \cdot442}{x} = \cdot169.$$

$$\therefore \quad x \times \cdot169 = 22{\cdot}32 \times \cdot442.$$

$$\therefore \quad x = \frac{22.32 \times \cdot442}{\cdot169} = 58{\cdot}37 \text{ Ans.}$$

By definition Sp. Ht. × At. Wt. = Atomic Ht. = 6·4.

$$\therefore \text{ At. Wt.} = \frac{\text{At. Ht.}}{\text{Sp. Ht.}} = \frac{6{\cdot}4}{\cdot107} = 59{\cdot}8 \text{ Ans.}$$

198. 1886. A.—Pure carbon-monoxide is passed over red hot copper oxide; the residual metal and the carbon dioxide formed are weighed. In one experiment 24·360 grams of oxygen were lost and 67·003 grams of carbon dioxide were obtained. From this calculate the atomic weight of carbon (O = 15·96).

$$CuO + CO = Cu + CO_2.$$

24·36 grams of O are lost. (See question).

The whole amount of O in the CO_2 formed = (24·36 × 2) = 48·72 grams.

Amount of C in the CO_2 = 67·003 − 48·72 grams.

$\therefore$ Weight of C in the CO_2 = 18·283 grams.

$$\frac{\text{Atomic weight of C}}{\text{Atomic weight of O}} = \frac{18{\cdot}283}{24{\cdot}36}.$$

$$\therefore \text{ Atomic weight of C} = \frac{\text{Atomic weight of O} \times 18{\cdot}283}{24{\cdot}36}.$$

$$\frac{15{\cdot}96 \times 18{\cdot}283}{24{\cdot}36} = 11{\cdot}978 \text{ the atomic weight of carbon.}$$

199. By dissolving ·7 grams of metallic cobalt in an acid, 292·3 cc. of hydrogen measured at 20°C and 756 mm pressure were produced. What is the atomic weight of the metal?

200 Berzelius found that 7·1724 grams of oxygen were present in 100 grams of litharge (PbO). Calculate the atomic weight of lead.

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201. Stas found, that after adding 7·25682 grams of potassic chloride to 10·51995 grams of silver dissolved in nitric acid, that ·0194 grams of silver remained in solution. Calculate the atomic weight of potassium.

202. Dumas, by heating 10,000 grains of silver in sulphur vapour, obtained 11481·5 grains of silver sulphide (Ag_2S). Find the atomic weight of sulphur.

203. 42·86 grams of chlorine combine with 100 grams of silver. What is the atomic weight of silver?

204. 100 grams of chromous chloride ($CrCl_2$) contain 57·5 grams of chlorine. Find the atomic weight of chromium.

204a. Auric sulphide contains 80·354 per cent. of gold. The specific heat of gold is 0·0316. Find the valency, atomic weight and equivalent of gold.

204b. Oxide of copper in a certain experiment yielded 79·8332 per cent. of pure metallic copper. The specific heat of copper is 0·09680; calculate its atomic weight, and give the formula for the oxide.

204c From a specimen of pure sulphide of lead 86·584 per cent. of lead was obtained. The specific heat of lead is 0·0315. Find the atomic weight of lead.

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XVIII.—MISCELLANEOUS PROBLEMS.

Gas Analysis.—Although no rule can be given for problems on gas analysis, in consequence of the variations in the process employed, yet, a few directions as to the method to be adopted in solving such problems may be given for the general guidance of the student.

The volumes of the gases experimented upon are carefully measured, and all allowances for variations in temperature and alterations of pressure must be taken account of.

A. **The Proximate Analysis** of a gaseous mixture is estimated by the successive absorption of the various gases by suitable reagents.

B. **The Ultimate Analysis** of a gaseous mixture is effected by the combustion of the mixture with oxygen; the quantities of each element present are deduced by calculations based upon the alteration of volume after explosion, the proportion of carbon dioxide obtained, and the volume of the remaining gas.

For example, in a given experiment a mixture containing Acc. of H, Bcc. of CH_4, Ccc. of C_2H_2, was burnt with oxygen gas; and the following data were recorded:—

Original volume of gas taken = x.
Volume of carbonic acid gas absorbed = y.
Reduction of volume due to combustion = z.

From the following equations:—

$$2H_2 + O_2 = 2H_2O$$
$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$C_2H_2 + 5O = 2CO_2 + H_2O$$

We have—

2 vols. of H require 1 vol. O and form 1 vol. of H_2O.
1 vol. of CH_4 requires 2 vols. O and forms 2 vols. of H_2O and 1 vol. CO_2.
1 vol. of C_2H_2 requires $2\frac{1}{2}$,, ,, ,, 1 ,, ,, ,, and 2 vols. CO_2.

The carbon dioxide produced, after exploding the mixture in an eudiometer tube, is estimated by absorption. The water vapour condenses, and so for all ordinary purposes may be regarded as occupying no space in the gaseous residue, this is, therefore, determined by contraction of volume.

We have, therefore, from the above x, the volume of mixed gases = A + B + C; y, the volume of carbonic acid gas = B + 2C; z, the contraction of volume = $\frac{3}{2}$A + 2B + $\frac{5}{2}$C; from which A, B, C, the volumes of the mixed gases, may be ascertained and expressed in terms of the measured quantities, x, y, z.

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Mixed Problems.—In working the following mixed problems, the student will find that it is necessary to employ in many cases several of the Rules given in the preceding articles in the solution of one problem. No general method can, therefore, be given, but the student may be advised to read with care the whole question proposed, and having decided in any particular case what is the first point of the question, to adopt one of the methods given in the earlier pages of this work for its solution, and then to proceed to employ any new data thus obtained in finding the answer required.

QUESTIONS.

205. 1867. A.—100 grams of a mixture of chloride of potassium and chloride of sodium have furnished 164·1 grams of potassio-chloride of platinum; what is the composition of the mixture?

$$\begin{array}{ccccc} 2\,KCl & + & PtCl_4 & = & K_2\,PtCl_6 \\ 2(39{\cdot}1 + 35{\cdot}5) & + & \{194{\cdot}5 + (35{\cdot}5)4\} & = & \{(39{\cdot}1)2 + 194{\cdot}5 + (35{\cdot}5)6\} \\ 149{\cdot}2 & + & 336{\cdot}5 & = & 485\,7. \end{array}$$

We see from above that 485·7 grams of potassio-chloride of platinum require 149·2 grams KCl for its production.

$\therefore$ 1 gram requires $\frac{149{\cdot}2}{485{\cdot}7}$ grams of KCl for its production.

$\therefore$ 164·1 require $\frac{149{\cdot}2 \times 164{\cdot}1}{485{\cdot}7} = 50{\cdot}41$ grams KCl.

Now this quantity of KCl was part of 100 grams of the mixture of KCl and NaCl and (100 − 50·41), *i.e.*, 49·59, is the quantity of NaCl.

Therefore the mixture contains 50·41 % KCl, 49·59 % NaCl.

206. 1877. A.—A sample of water contains, in solution, in 100,000 parts, 16 parts of Calcic carbonate, 5 parts of calcic sulphate, and 7 parts of common salt; what is its hardness, and how much will this hardness be reduced by boiling for half-an-hour?

By question 100,000 parts H_2O contain (16 + 5 + 7) = 28 parts of salts.

$\therefore$ 100,000 grains H_2O contain 28 grains salt.

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But a gallon of water = 277·27 cubic inches = 277 27 × 252·89 = 70118 grains.

∴ 100,000 grains of H_2O contain 28 grains salts.

1 grain ,, contains $\frac{28}{100,000}$.

70118 grains (1 gallon) contain $\frac{28 \times 70118}{100,000} = 19{\cdot}63$ grains salts.

But by definition one degree of hardness corresponds to one grain of salt per gallon, therefore the hardness of the water is 19·63 degrees.

By boiling for half-an-hour the dissolved $CaCO_3$ is precipitated as follows—

$$CaH_2(CO_3)_2 + \text{heat} = CaCO_3 + H_2O + CO_2.$$

And there being 16 grains of dissolved $CaCO_3$ in 100,000 grains, there remains dissolved the NaCl and $CaSO_4$ (unaltered by boiling). Therefore $\frac{28 - 16}{28}$ of the original hardness is permanent $= \frac{12}{28}$ of 19·63 = 8·413 degrees remain after boiling for half-an-hour.

(19·63 - 8·41) = 11·22 amount reduced.

207. 1880. A.—What increase in weight will occur on burning 10 grams of phosphorus in a tube through which oxygen is passed, supposing that none of the product be lost? How would you regain the phosphorus from the substance formed?

$$P_2 + 5O = P_2O_5.$$

$$62 + 5(16) = (62 + 80.)$$

62 grams of P will take up 80 grams of O.

1 ,, ,, $\frac{80}{62}$,,

10 ,, ,, $\frac{800}{62} = 12{\cdot}903$ grams increase in weight.

208. 1882. A.—The current from a battery liberates in a given time 150 cbc. (measured at 0°C and 760 mm.) of the mixed gases from acidified water; if this same current were passed through a solution of copper sulphate, what weight of copper would be deposited? (Cu = 63·0.)

$$H_2O = H_2 + O.$$

2 vols. = 2 vols. + 1 vol.

3 vols. of mixed gases are produced from 2 vols. of H_2O.

∴ 150 ,, ,, ,, 100 ,,

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As 150 cbc. of the mixed gases are produced from 100 cbc. of water gases, and there are 100 cubic centimetres of H produced. A litre = 1000 cbc.

A litre of H weighs ·0896 grams.

∴ 100 cbc. of H weigh ·00896 grams at 0°C and 760 mm. pressure.

Now the chemical equivalent of copper is $\frac{63}{2} = 31{\cdot}5$. Copper is a dyad, so that for 1 gram of H produced we should have by the same current for same time 31·5 grams Cu deposited. So for ·00896 grams H we should have

$$\cdot00896 \times 31{\cdot}5 = \cdot28224 \text{ grams Cu.}$$

282·24 milligrams Cu.

209. What is the weight of a cubic metre of hydrogen at normal temperature and pressure?

210. What weight of potassic bromate can be obtained by neutralizing 520 grams of bromine with potash?

211. Required the percentage of real acid contained in 1·483 grams of aqueous acetic acid, which evolves ·427 grams of carbonic acid on adding it to bicarbonate of sodium.

212. What is the volume of nitrogen measured at 150°C which is given off on heating 20 grams of ammonium bichromate?

213. If 159·97 parts by weight of lead nitrate contain 100 parts of lead, what is the atomic weight of the metal?

214. 10 grams of potassium tetroxide are thrown into water and the solution boiled, what is the volume of the oxygen measured at 100°C and 760 mm. given off.

215. A spherical balloon with a radius of 50 feet would hold *(a)* how many pounds of hydrogen? *(b)* how many pounds of nitrogen? *(c)* how many pounds of air? *(d)* how many pounds of oxygen?

216. Calculate the amount of water present in 100 parts by weight of the compound $Na_2CO_3 + 10H_2O$. Give the scientific and commercial names of the salt?

217. What volume of hydric sulphide will be evolved by dissolving 25 milligrams of pure ferrous sulphide in sulphuric acid?

218. Some pieces of copper weighing 50 milligrams were completely converted into copper oxide by heating in air. What volume of oxygen at N.T.P. was used, and how much air would be required to yield this quantity of oxygen?

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219. 1000 grms. of copper oxide are placed in a glass tube which is then heated and a current of pure hydrogen is passed through the tube; what will be the chemical action, and what the weights of the substances separately produced? (H : O : Cu = 1 : 16 : 63·5).

220 A solution of a lead salt was precipitated by sulphuric acid, and the precipitate weighed 20 grams. How much lead was there in the solution? (Pb = 207.)

221. How much neutral carbonate of sodium will 1000 grains of the bi-carbonate produce? (Na = 23.)

222. How many cubic centimetres of (*a*) carbon dioxide (*b*) nitrogen gas, measured at 0°C and 760 mm. pressure, will be given off by burning two grams of English musketry powder, supposing that the decomposition is a simple one?

223 How many cubic centimetres of oxygen are contained in 100 cubic centimetres of air? How much hydrogen in cubic centimetres would be burnt by this quantity of oxygen?

224. How much oxygen is contained in 10,000 grams of potassic dichromate? How much oxygen is given off when the same quantity of the salt is treated with an excess of oil of vitriol? (K = 39, O = 16, Cr = 52·5.)

225. How many grams of potassium cyanide and sulphuric acid shall I require in order to produce 50 grams of pure hydrocyanic acid?

226. How much blue vitriol can be obtained from 500 grams of cupric oxide?

227. What volume of hydrogen sulphide, at 10°C and 780 mm. pressure, is required to precipitate the mercury from a solution which contains 63 milligrams of cyanide of mercury?

228. What is the percentage of water contained in copper sulphate?

229. How many grams of sodium metaphosphate can be obtained by heating 50 grams of microcosmic salt?

230. What are the proportions by weight of the constituent elements of the following compounds:—Marsh gas, olefiant gas, carbonic acid gas, and water?

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231. How much carbon could be completely burned by one ton of ordinary air?

232. How many litres of pure hydrogen sulphide will be required to completely precipitate the copper as copper sulphide from a solution containing 374 grams of copper nitrate $Cu(NO_3)_2$?

233. What weight of hydrogen sulphide must be used in order to completely precipitate as bismuth sulphide the whole of the bismuth present in a solution containing 835 milligrams of bismuth nitrate?

234. How many grams of phosphoric pentoxide will be formed by burning 17·712 grams of phosphorus in oxygen?

235. What quantity, in litres, of hydrobromic acid would be produced by the action of 10 grams of bromine on phosphorus and water, and how much phosphorus would be used during the operation?

236. What weight of carbonic oxide (carbon monoxide) will be produced by the action of 10 milligrams of sulphuric acid on formic acid?

237. How many litres of a mixture of hydrogen sulphide and hydrogen, containing 10 per cent. of hydrogen, would be required to precipitate the lead from a solution containing 30 grams of lead nitrate?

238. What is the percentage composition of chrome alum? How much chromium is there in 35 grams of this body?

239. What number of grams of ammonic hydrate will be required in order to precipitate all the iron from a solution containing 112 grams of ferrous sulphate?

240. Sulphuric acid was used to precipitate the lead as lead sulphate from a solution of a lead salt. The precipitate weighed, when dry, 40 grams. How much lead was there in the solution?

241. The whole of the copper present in a solution of copper sulphate was precipitated by the use of potassic hydrate; the precipitate was dried and found to weigh 35 milligrams; what was the quantity of copper present in the solution?

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242. If the whole of the copper present in a solution containing 1·0247 grams of copper sulphate be converted into copper oxide; what will be the weight of the resulting oxide?

243. By adding a solution of silver nitrate to a solution containing sodium chloride, ·9956 grams of silver chloride were produced; what quantity of sodium chloride was present in the solution?

244. How many grams of potassium cyanide and sulphuric acid shall I require in order to produce 75 grams of hydrocyanic acid?

245. What weight of pure potassic cyanide must be treated with hydrogen sulphate in order to produce 68 litres of hydrocyanic acid at normal temperature and pressure?

246. What quantity of ammonic carbonate would be required to precipitate the whole of the barium as barium carbonate from a solution containing 35 grams of barium chloride?

247. The whole of the zinc present in a solution of zincic chloride is precipitated as zincic sulphide; by the use of hydric sulphide, this precipitate when weighed is found to be 97 grams; what was the quantity of zinc present in the solution?

248. The silver present in a solution of silver nitrate is all precipitated as silver chloride which is found to weigh 285·2 milligrams; what quantity of silver was present in the solution?

249. What is the percentage composition of common potash alum?

250. How many cubic centimetres of nitrogen gas can I obtain by heating 128 grams of ammonium nitrite?

251. What is the weight in grammes of 1 litre of cyanogen gas?

252. State the formula and the percentage composition of cane-sugar.

253. The formula of urea is $(NH_2)_2CO$. What is the percentage composition?

254. Give the formula and percentage composition of marsh gas.

255. What is the empirical formula of a substance possessing the following percentage composition:—

Carbon, 40·00.
Hydrogen, 6·66.
Oxygen, 53·34.

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256. Give the formula and percentage composition of common alcohol.

257. Give the formula and percentage composition of formic acid and oxalic acid.

258. What is the empirical formula of a substance which yields the following results on analysis :—

Carbon, 20·00,
Hydrogen, 6·66,
Oxygen, 26·67,
Nitrogen, 46·67 ?

259. The double salt formed by hydrochlorate of morphine and platinic chloride yields on ignition 20·14 per cent. of platinum. Calculate the molecular weight of morphine.

260. An organic compound yielded on analysis the following results :— Carbon, 23·76; Hydrogen, 5·94; Chlorine, 70·30. What is its empirical formula ?

261. What organic compound is formed by the prolonged action at 100°C of potassic hydrate upon carbonic oxide ? Calculate the percentage composition of the body.

262. What is the empirical formula of an organic compound which yielded on analysis the following numbers :— Carbon, 22·75; Hydrogen, 2·84; Oxygen, 30·33; Chlorine, 44·08 ?

263. Give the formula and percentage composition of cyanogen and benzol.

264. 4·144 gram of an organic compound containing the elements C, H, I and N, yielded on analysis ·5 gram carbonic anhydride and ·1055 gram water. ·497 gram of the same compound yielded ·5335 gram of argentic iodide. Required the empirical formula of the compound.

265. Give the formula and percentage composition of acetic ether, and benzoic acid.

266. A substance gave the following numbers on combustion :—0·35 gram gave ·881 gram carbonic anhydride and ·158 gram water. It contained only the elements carbon, hydrogen and oxygen. Find empirical formula of the compound.

267. Give the percentage composition of lactic acid.

268. Give the formula and percentage composition of acetic aldehyde.

269. The ultimate analysis of an organic compound containing carbon, hydrogen, and oxygen, gave the following result :— Carbon, 52·17; Hydrogen, 13·04; Oxygen, 34·79. What is the empirical formula of the compound ?

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270. Give the formula and percentage composition of methylic formate.

271. The ultimate analysis of an organic compound consists of Carbon, Hydrogen, and Oxygen, gave the following result:—3 grams yielded ·5738 gram carbonic anhydride, and ·3521 gram water. Give the percentage composition and empirical formula of compound.

272. Give the formula and percentage composition of acetic ether.

273. An organic compound gave the following numbers on analysis:—Carbon 26·66, Oxygen 71·12, Hydrogen 2·22. What is the empirical formula?

274. Calculate the empirical formula of an organic compound yielding the following percentage composition:—Carbon 48·66, Hydrogen 8·10, Oxygen 43·24.

275. How many litres of Oxygen will be required in order to burn completely a mixture of one litre of marsh gas and one litre of ethylene?

276. Give the formula and percentage composition of Butyric ether.

277. Calculate the percentage composition of oxalic acid.

278. Required the empirical formula of an organic body having the following percentage composition:—Carbon 73·84, Hydrogen 13·84, Oxygen 12·32.

279. The vapour of phenol (carbolic acid) is passed over heated zinc dust, by which means oxygen is withdrawn. What is the name, formula, and percentage composition of the hydro-carbon, thus (*obtained*) formed?

280. In order to burn completely two litres of the following gases, what volume of oxygen will be needed and what volume of CO_2 will be formed:—Methane, Olefiant gas, Ethyl-hydride?

281. What is the simplest formula for a hydro-carbon containing 84 % of Carbon and 16 % of Hydrogen? Also give the density (H = 1) and its molecular weight.

282. Calculate the percentage composition of acetic acid. Mention the acetates least soluble in water.

283. 50 volumes of a gas mixed with 70 volumes of oxygen gave, after explosion, 50 volumes of carbon dioxide; and after its absorption by potash 45 volumes of oxygen; what was the gas?

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284. ·25 grams of a hydro-carbon gave on combustion ·8085 CO_2 + ·2655 H_2O. Explain how from the above numbers you deduce an empirical formula; give the simplest formula to which the above numbers lead.

285. 11·2 litres of cyanogen at 0°C and 760 mm. are burnt. What will be the products of the combustion, and what bulk will they occupy measured at 0°C and 760 mm.?

286. 342 milligrams of glacial acetic acid are burnt in a combustion tube in the ordinary way. What increase in the potash bulb, and what in the calcium chloride tube would you expect to find if the combustion is carried out properly?

287. How many grams of oxygen will be needed to burn completely 500 cc. of Ethane, measured at 0°C and 760 mm., and what diminution of volume will occur when the residue is treated with potash?

288. Give the molecular formula and calculate the percentage composition of sugar of lead (Pb = 207).

289. How many litres of oxygen are required for the complete combustion of 15 grams of methyl alcohol? What volume of CO_2 will be formed?

290. The percentage composition of a body is Carbon, 54·55; Hydrogen, 9·09; Oxygen, 36·36. What is its empirical formula?

291. How would you obtain ethane (ethyl-hydride) from ethyl iodide? What bulk of this gas measured at 0°C and 760 mm., could be obtained from 10 grams of ethyl iodide?

292. Sketch the apparatus used for determining the C and H in organic compounds. If 460 milligrams of alcohol are burnt, what increase in weight of the potash bulbs would you expect to find?

293. Calculate the percentage composition of the organic liquid obtained by the action of H_2SO_4 on alcohol. How many volumes of O are required to burn completely two volumes of this compound when in the state of gas?

294. Give the formula and percentage composition of marsh gas. What action, if any, has chlorine on it?

295. If 100 vols. of olefiant gas (ethylene) be mixed with 500 vols. of oxygen and exploded, what volume of gas will remain, and how much of it will be carbon monoxide?

296. Calculate the percentage composition of a hydro-carbon from the following data:—Weight of substance ·25; Carbon-dioxide ·8085; Water ·2655.

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297. How many cubic centimetres of oxygen at normal temperature and pressure are required to burn completely (1) 500 cc. of marsh gas, (2) 500 cc. of the vapour of ethyl alcohol?

298. What volume of gas measured at 0°C and 760 mm. would you obtain by treating 10 grams of oxalic acid with sulphuric acid?

299. How many times heavier is ether vapour than hydrogen? What weight of oxygen is necessary to burn completely at normal temperature and pressure 5 litres of ether vapour?

300. ·333 gram of a non-nitrogenous body gave when burnt ·4885 gram of carbon dioxide and ·2099 gram of water. Calculate its empirical formula.

301. One hundred cc. of air are passed over red hot charcoal. Would any alteration take place in volume?

302. How many litres of oxygen gas measured at 10° C. and 755 mm. can be obtained from 1 kilogram of potassium chlorate?

1 litre of oxygen at 0° C. and 760 mm. = 1·43 grams.

303. What do you understand by the density of a gas? The volume of a given weight of a gas has to be calculated at the standard temperature and pressure. What does this mean?

304. What weight of pure nitric acid would contain 100 grams of oxygen; and what weight of pure hydrochloric acid would contain 100 litres of chlorine at the standard temperature and pressure?

305. Express in English weights and measures 500 grams, 500 cubic centimetres, 500 millimetres. Find the weight in grams of 350 cc. of sulphuric acid of density 1·8.

306. 1 lb. of sulphur may combine with 1 lb. of oxygen or with 1½ lbs. of oxygen; what compound is formed in each case?

307. What weight of oxygen gas could be obtained by the complete decomposition of 100 grams of pure potassium chlorate? If the chlorate used contained 10 per cent. of its weight of potassium chloride, what would be the difference in the amount of oxygen obtained?

308. Calculate the vapour density of ammonium chloride. By experiment it is found to be 13·345. How do you explain the difference between the calculated and observed results? Can you give any experimental evidence in support of your explanation? Do you know of any other similar cases?

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309. Calculate the formula of a body which has the following percentage composition :—

Magnesium - - - - - - -	3·98
Calcium - - - - - - - -	13·28
Potassium - - - - - - -	12·99
Sulphuric acid (SO_4) - - - -	63·77
Water - - - - - - - -	5·98
	100·00

310. 2·0876 grams of hydrogen when passed over heated oxide of copper yielded 18·7406 grams of water. Calculate the atomic weight of oxygen.

311. 300 cc. of a solution of caustic potash containing 40 grams of KHO per litre is required to neutralize 100 cc. of sulphuric acid, and the same volume of nitric acid. Calculate the amount of acid in each solution.

312. One gram of iron is converted into ferric chloride, and the product is dissolved in water. What volume, at normal temperature and pressure, of hydrogen sulphide is theoretically required to completely reduce the ferric chloride to ferrous chloride.

313. The combining weight of sulphur being 32 determine the density of sulphuretted hydrogen as compared with hydrogen. And the density of phosphoretted hydrogen (PH_3) being 17·25 times that of hydrogen, find the combining weight of phosphorus.

314. Give the formulæ of the two carbonates of sodium, and explain how the one may be converted into the other. How much neutral carbonate will 1,000 grains of the bicarbonate produce?

315. Find the formula of a salt having the following percentage composition :—Magnesium, 9·76
Sulphur, 13·01
Oxygen, 26·01
Water, 51·22
100·00

316. One hundred parts by weight of silver chloride consist of 75·27 parts by weight of silver and 24·73 of chlorine. Assuming that the molecule of silver chloride consists of one atom of silver to one of chlorine, what will be the combining or atomic weight of silver?

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317. 3·404 grms. of a compound consist of 1·564 grms. of potassium, ·56 grms. of nitrogen, and 1·28 grms. of oxygen. Calculate a formula for the substance. What is its name?

318. Give examples of efflorescent and deliquescent salts. Of what practical use are some of the latter? Calculate the amount of water present in 100 parts by weight of the compound ($Na_2CO_3+10H_2O$.) Give the scientific and commercial names of this compound. Is it an efflorescent or deliquescent substance?

319. Write down the formulæ of silver nitrate, sodium chloride, potassium chloride, calcium chloride. How much sodium chloride, potassium chloride, calcium chloride, respectively, would be needed to precipitate all the silver from 17 grammes of silver nitrate?

320. It is said that it is injurious to breathe air containing ·07 per cent. by volume of carbon dioxide. Now one man will exhale about 260 grams of carbon dioxide in 8 hours. Supposing that for 8 hours he remains in a room which is not ventilated, and which has a capacity of 23,000 litres, will the air in the room at the end of that time be fit to breathe or not?

321. Common soda crystals have the formula, $Na_2CO_3 + 10H_2O$. On exposure to the air they undergo a change, and the resulting substance has the formula $Na_2CO_3 + H_2O$. What is the nature of the above change? Supposing that 100 lbs. of soda crystals undergo the above change, what will be the weight of the resulting substance?

322. A certain compound weighs 25 grammes and contains 10 grammes of calcium, 12 grms. of oxygen, and 3 grms. of carbon. Give its formula and name. How does it occur in nature?

323. Supposing that a certain water contains 20 grains of calcium carbonate in a gallon, and that the following equation represents the action of a solution of soap ($NaC_{18}H_{35}O_2$), on calcium carbonate

$$2NaC_{18}H_{35}O_2 + CaCO_3 = Ca(C_{18}H_{35}O_2)_2 + Na_2CO_3,$$

calculate how much soap will be decomposed by a gallon of the water, when the atomic weights of sodium, carbon, oxygen, and calcium, are taken as (Na = 23, C = 12, O = 16, Ca = 40).

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324. How much carbon is there in 100 grammes of marsh gas? How many litres of carbon dioxide would be produced by the complete combustion of this quantity of marsh gas?

325. State the law of combination by weight in multiple proportions. Shew that this law is illustrated in the cases of the two oxides of carbon, the percentage compositions of which are as follows: C 42·86 and O 57·14.
C 27·27 and O 72·73.

326. Glauber salts (Na_2SO_4, $10H_2O$) changes on exposure to the air, and becomes converted into a compound having the formula Na_2SO_4. What is the nature of this change, and what is it called? Calculate the change of weight that occurs when 100 lbs. of Glauber's salt has undergone the above change.

327. An analysis of a compound gave the following composition in 170 parts by weight, S,40, O,80, Ca,50. Determine a formula for the compound, and give its chemical name. Mention the chief properties of the compound. Does it occur in nature? If so, in what way? (S=32, O=16 and Ca = 40.)

328. What weight of hydrochloric acid would be necessary in order to completely decompose one gram of silver nitrate?

329. Find the molecular weight of an element, 1 gram of which in the state of vapour fills the same space that ·016 gram of hydrogen fills at the same temperature and pressure.

330. Calculate what volume of chlorine could be obtained from 117 grams of sodium chloride, the gas being measured at 13·65°C and 798 mm.

331. An excess of pure hydrogen passed over 25 grammes of heated copper oxide gave 5·7 grammes of water, and 19·93 grammes of metallic copper. State the conclusions you would draw from this experiment.

332. Give some account of the preparation and properties of carbon mon-oxide. What weight of oxygen will be necessary to burn completely 33·6 litres of this gas measured at 0°C and 760 mm.? A litre of H at 0°C and 760 mm. weighs ·0896 grams.

333. The analysis of a compound gave as its percentage composition—Sodium 29·11, Sulphur 40·51, Oxygen 30·38. Calculate the formula of the compound. Name the salt and mention any of its useful applications.

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334. What volume of chlorine measured at 15°C and 770 mm. may be obtained by the action of hydrochloric on 200 grams of manganese dioxide?

335. State the law of gaseous diffusion. 12 litres of a gaseous compound diffuse through a given apparatus in the same time as 9 litres of oxygen. What is the molecular weight of the compound?

336. Describe the preparation and give the leading characters of marsh gas (methane). Four volumes of this gas are mixed with sixteen volumes of oxygen and the mixture fired by the electric spark. State the nature and volume of the resulting products, all the measurements being made at constant temperature.

337. The analysis of a compound gave the following as its percentage composition :—Sodium, 27·05; nitrogen, 16·47; oxygen, 56·48. Calculate the formula of the compound and state any uses to which the body is applied.

338. Calculate what weight of sulphuric acid will just neutralize 1 gram of each of the following substances respectively :—caustic potash, ammonia, sodium carbonate.

339. How much zinc would be required to produce sufficient hydrogen gas to fill a balloon of 10,000 litres capacity at 0°C and 760 mm. pressure?

340. A given powder is composed of 32 grams of sulphur, and 56 grams of iron. How would you ascertain whether the powder is a mechanical mixture or a chemical compound?

341. What volume of sulphuretted hydrogen at 0°C and 760 mm. pressure, can be prepared from 10 grams of iron sulphide by the action of an acid?

342. A kilogram of dilute sulphuric acid is found to dissolve 130 grammes of zinc. Find the percentage by weight of strong H_2SO_4 in the dilute acid, and the volume of hydrogen (at 0°C and 760 mm.) evolved.

343. Find the empirical formula of a substance the analysis of which yields the following results :—

Carbon	20·00
Hydrogen	6·67
Nitrogen	46·67
Oxygen	26·66
	100·00

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344. A compound of phosphorus, oxygen, and chlorine was found to contain phosphorus 20·19 per cent., oxygen 10·43 per cent., chlorine 69·38 per cent. Specific gravity of the compound as gas = 77·95 (H = 1). Specific heat of phosphorus = 0·17. From these data determine the molecular formula of the compound and the atomic weight of phosphorus.

345. Three grams of the oxide of a metal after being heated in a current of hydrogen left 2·393 grammes of the metal. The specific heat of the metal is ·101. Calculate its atomic weight, explaining each step in the operation.

346. Three litres of CO_2 are passed over a long column of red hot carbon; the resulting gas is then passed over an excess of heated Fe_2O_3: state the changes that occur in the volume and composition of the gas.

347. Shew how the formula of nitric oxide may be deduced from the following data: 15·6 cc. of the gas passed over heated Cu gives 7·8 cc. of nitrogen; the weight of nitric oxide which fills a certain globe is 3·75 grams, the weight of an equal volume of hydrogen being 0·25 gram.

348. A tube contains 45 cc. of hydrogen and 20·25 cc. of oxygen at a temperature of 120°C; in what respect do the contents differ from steam at the same temperature? What effects would be observed on passing a spark through the tube? What laws regulate the combination of gases by volume?

349. Give examples in illustration of your answer. Calculate the composition of a compound of carbon and hydrogen from the following data:—5·2 cc. of the gas exploded with 20·0 cc. of oxygen left 14·8 cc. of residue; 10·4 cc. of this residue was absorbed by KHO, and the remainder kindled a glowing taper. Define the terms equivalent weight and atomic weight.

350. Given that ·1 gram of an element on solution in HCl displaced 124·4 cc. of hydrogen at 0°C and 760 mm.; further that the specific heat of the metal is ·214, calculate its atomic weight and write down the formula for its oxide and chloride.

351. An acid whose normal sodium salt is perfectly neutral forms two classes of salts with monad metals. A mass of the acid weighing 2·45 grams is found to require 2 grams of

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sodium hydroxide for complete neutralization. What conclusions would you draw from these data

H : O : Na = 1 : 16 : 23?

352. If the oxides of a substance contain respectively 36·8 per cent., and 22·54 per cent. of oxygen, how would you show that the combination is in multiple proportions?

353. A piece of metal weighing 1·296 grams dissolved in dilute sulphuric acid, the solution evaporated to dryness, and the excess of acid expelled by heat gave 2·41 grams of residual sulphate. Find the equivalent weight of the metal.

354. A hydrocarbon has been found to yield on analysis 92·30 per cent. of carbon. The vapour density of the hydrocarbon being given as 39(H=1), deduce its molecular formula. Explain each step in the calculation.

355. A piece of iron weighs 10 lbs. in air, a lump of platinum which weighs 15 lbs. in air and 9 in mercury, being used as a sinker, the iron and platinum together are found to weigh 1 lb. in mercury. Find the Sp.Gr. of iron, that of mercury being 13·5.

356. A piece of glass weighs 50 grains in air, and 34 in alcohol. Find the Sp.Gr. of alcohol, that of glass being 2·5.

357. Find the Sp.Gr. of wood, if a block which weighs 4 lbs. in air weighs 9 lbs. when immersed in water and attached to a sinker of lead weighing 11 lbs. in air and 10 in water.

358. A piece of metal weighs 6 lbs. in air. To it a piece of platinum which weighs 5 lbs. in mercury is attached as a sinker, and the two together weigh 2 lbs. in mercury. Find the Sp.Gr. of the metal if that of mercury be 13·5.

359. A silk baloon, 40 feet in diameter, weighs 80 lbs. It is filled with hydrogen gas of Sp.Gr. = ·0694 (Sp.Gr. of air = 1). What weight will be required to prevent the ascent of the balloon?

360. An unknown quantity of potassium bromoaurate, $AuBr_3KBr$, on being heated, left 9·92451 grams of a mixture of metallic gold and potassium bromide. The mass on being treated with water, left 6·18997 grams of gold. The solution of KBr required 3·38540 grams of silver for total precipitation by Stas's method, and afforded 5·89143 grams of silver bromide. These data afford three independent values for the atomic weight of gold which you are required to calculate.

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361. Calculate the vapour density of an organic liquid from the following data obtained by the Hoffman method :—

Weight of liquid	0·338 gram.
Vol. of vapour	109·80 cc.
Temp.	99·50°C.
Bar.	746·9 mm.
Height of col.	283·4 ,,

362. How can the density of a gas be determined from its rate of diffusion. If a gas diffuses 1·0143 times as rapidly as air, what is its density? A hydro-carbon which has the vapour density 50 gave the following numbers on analysis :—0·3500 gram gave 1·0754 gram CO_2 and 0·5050 gram water. Calculate the formula of the body.

363. Six grams of anhydrous magnesium sulphate are dissolved in 100 grams of water; the observed depression of the freezing point is 0·958. Taking the value of T as 37, what formula most probably represents the state of the dissolved salt?

364. The eudiometrical investigation of a gaseous mixture yielded the following results. Give the percentage of C_2H_2 and CH_4 contained in it :—

I.	Corrected for temp. and pressure.
Volume of gas used	137·06
,, after action of SO_2	137·03
,, after removal of specimen for combustion	103·38
,, after action of alcohol	53·72

II.	Corrected to 0° and 1m. pressure.
Volume of gas used	10·86
,, after admission of O	154·20
,, after explosion	129·71
,, after absorption of CO_2	112·88
,, after admission of H	523·19
,, after explosion	184·54

365. 0·213 gram of a carbinol yielded on combustion 0·566 gram CO_2, and 0·265 gram H_2O. Required its empirical formula.

366. Calculate the vapour density of a terpene from sage oil from the following experimental data, obtained in a determination made by Hoffman's method :—

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Observed height of barometer at 17° = 755 m.
Observed height of mercury in tube at 155° = 561 m.
Volume of vapour - - - - - - - - - 73·28 cc.
Temperature of vapour - - - - - - - 185°C.
Weight of vapour - - - - - - - - 0·0682 gram.
Co-efficient of expansion of mercury = 0·00018.
Show that the experimental agrees with the calculated density.

367. Required the molecular weight and formula of a monobasic acid from the following data :—Weight of acid taken 0·3295 gram, gave 0·8233 gram CO_2 and 0·3437 gram H_2O, 0·6103 gram silver salt yielded 0·2491 gram Ag.

368. A hydride of the series $C_n H_{2n+2}$ contains according to combustion analysis 83·5 per cent. of carbon. By what experimental means would you ascertain the molecular weight of this compound?

369. Calculate the molecular formula and vapour density of a hydrocarbon from the following numbers :—
(1) Combustion analysis 0·1237 gram of a substance taken gave 0·4282 CO_2, and 0·0626 H_2O.
(2) Vapour density by Victor Meyer's method. Barometer 718·3mm. tension of vapour 11·91mm. Temperature of air in tube 14°C. Weight of substance taken 0·16175 grams. Volume of air displaced 16·2 cc.

370. A compound containing carbon, hydrogen, nitrogen, and oxygen is burnt. 0·217 gram gave 0·1005 water and 0·4805 carbon dioxide. The compound also contained 7·82 per cent. of nitrogen. Required its simplest formula.

371. An organic body containing 47·1 per cent., 5·8 per cent. of hydrogen, and 47·1 per cent. of oxygen yields in contact with water a monobasic acid whose silver salt contains 64·68 per cent. of metal; what is the molecular formula and name of the organic body? (Ag. = 108.)

372. Calculate the molecular formula and vapour density of a hydrocarbon from the following numbers :—(1) Combustion analysis. Substance taken 0·1310 gram., $CO_2 = 0·4505$. $H_2O = 0·0705$. Vapour density by Meyer's method. Substance taken 0·1105 gram. Temp. 17·5°C. Barometer 754·1 mm. Volume of air 13·2 cc. Tension of aqueous vapour 14·882 mm.

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373. 0·571 grams of a monobasic acid gave on combustion 1·4362 grams of carbon dioxide, and 0·2547 grams of water; 0·2143 grams of the silver salt of this acid gave 0·101 grams of silver. Give the formula and the percentage composition of the acid.

374. Calculate the vapour density of a compound from the following data:—

(*a*) **Victor Meyer's Method.**—Weight of substance used 0·0585 gram. Volume of air expelled 9·8 cc. Temperature 16°C. Barometer 732·7 mm.

(*b*) **Hoffmann's Method.**—Weight of substance used 0·1366 gram volume of vapour 101·9 cc. Temperature of vapour 140°C. Height of mercury column 503·5mm. Barometer 730·9mm. at temperature of 24·7°C. The coefficient of expansion of mercury is 0·00018.

375. A silver salt of an organic monobasic acid gave the following analytical results:—

(1) 0·2065 substance gave 0·2025 CO_2 and 0·076 H_2O.

(2) 0·259 substance gave 0·12475 Ag.

Required the formula and molecular weight of the acid.

376. The analysis of a compound gave the following percentage numbers; what was its molecular and constitutional formula, on the supposition that the molecule contained one atom of zinc, Zn. = 65?

Carbon	19·75
Hydrogen	4·11
Nitrogen	23·04
Zinc	26·75
Oxygen	26·35
	100·00

377. In the investigation of an organic compound the following data were obtained:—

Carbon	62·07
Hydrogen	10·35
Oxygen	27·58
	100·00

Vapour density 4·04 (atmospheric air = 1). What is the molecular formula of the compound?

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378. In the determination of the vapour density of an organic compound by Gay Lussac's method, the following data were observed :—

Weight of liquid used	·167 gram.
Observed volume of vapour	46·5 cc.
Temperature	190°·5 C.
Height of barometer	738·1 mm.
Height of inner column of mercury corrected for pressure of column of oil	10·0 mm.

What was the molecular weight of the compound?

379. What is the weight of 100 cc. of air at the standard temperature and pressure?

380. Calculate the empirical formula of a substance which has the following percentage composition :—

Carbon	40·00
Hydrogen	6·67
Oxygen	53·33
	100·00

381. Calculate the percentage composition of any organic substance known to you, and show how the simplest formula for the body is derived from the numbers.

382. A gas measures 117·9 cubic inches at 9·9° C., and 700·9 millimetres mercurial pressure. Required its volume at 0°C and 1 metre mercurial pressure.

383. How much white marble would you require to produce 1 cwt. of chloride of calcium, and what other material would be necessary for the transformation?

384. An analysis of a salt gave the following numbers; what is its empirical formula?

Sulphur	22·53
Sodium	32·39
Oxygen	45·08
	100·00

385. What is the weight of 1 litre of chloroform gas at $0^{m}\cdot76$ Bar. and 273°C?

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386. A mixture consisting of 1 litre of olefiant gas at 100°C, and 1 litre of chlorine likewise at 100°C is for some time exposed to the action of sunlight, the temperature remaining the same. What is the volume and the composition of the product of the reaction?

387. Supposing sugar to yield by fermentation alcohol and carbonic acid alone, how many grams of absolute alcohol, and how many litres of carbonic acid are found by the fermentation of 1 kilogram of cane sugar?

388. How many grams of urea can be prepared from 100 grams of pure cyanide of potassium?

389. 100 litres of phosphoretted hydrogen (H_3P) at 100°C are mixed with 300 litres of chlorine at 100°C. How many litres of chloride of phosphorus gas, and how many litres of hydrochloric acid, both measured at 100°C are produced?

390. How many grams of phosphorus are required for the production of 100 grams of pyrophosphate of magnesium?

391. 100 grams of a mixture of chloride of potassium and chloride of sodium have furnished 164·1 grams of potassio-chloride of platinum; what is the composition of the mixture?

392. What is the empirical formula of a substance possessing the following percentage composition?

Carbon	40·00
Hydrogen	6·66
Oxygen	53·34
	100·00

393. Give the formula and percentage composition of common alcohol.

394. The analysis of an organic compound containing carbon, hydrogen, and oxygen, gave the following experimental data:—

Substance burnt	·3000 grams.
CO_2 produced	·5738.
H_2O „	·3519.

The vapour density of the substance, referred to the specific gravity of hydrogen as unity, was found to be 23. What is the percentage composition and the rational formula of the compound? What is the specific gravity of the vapour of amylic alcohol, the density of hydrogen being taken as unity?

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395. Describe the mode of determining the density of a vapour by Gay Lussac's and by Dumas' process. In the determination of a vapour density by the former process the following data were obtained :—

Weight of substance	·1163 gramme.
Observed volume of vapour	50·77 cubic centimetres.
Height of barometer	755·5 millimetres.
Difference of height of mercury inside and outside of tube	80·0 ,,
Height of spermaceti or oil column reduced to millimetres of mercury	16·9 ,,

Required the specific gravity of the vapour, the density of hydrogen being taken as unity, also the weight of one litre at 0°C and 760 barometrical pressure.

396. The quantitative analysis of a gas suspected to contain ethylic hydride, carbonic oxide, and hydrogen, gave the following data :—

Volume of combustible gas	32
Contraction on explosion with excess of oxygen	46
Volume of CO_2 generated	17

What was the percentage composition of the gas by volume ?

397. What is the empirical formula of a substance which yields the following results on analysis ?

Carbon	20·00
Hydrogen	6·66
Oxygen	26·67
Nitrogen	46·67
	100·00

398. What is the weight, in grammes, of 1 litre of ethyl gas, measured at 0°C and 760 mm. pressure ?

399. In the eudiometrical analysis of a hydrocarbon gas the following numbers were obtained : Fill up the last column of corrected numbers, and give the molecular formula and name of the gas.

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	Observed vol.	Temp. C.	Difference of Mercury Level.	Height of Barometer.	Corrected vol. of Dry Gas at 0°C and 1 metre pressure.
Gas used moist - -	91·8	12·8°C	623·1mm	752·7mm	
After admission of oxygen (moist) -	535·1	12·9°C	160·6 ,,	751·7 ,,	
After combustion (moist)	498·8	12·8	194·0 ,,	751·1 ,,	
After absorption of CO_2 (dry) - -	454·3	13·0°	237·2 ,,	741·5 ,,	

The tension of aqueous vapour at the above temperature is—

At 12°·8 - - - 11·0 mm. of mercury.
,, 12°·9 - - - 11·1 ,, ,,

400. What increase in weight would you expect to find in the KHO bulbs and in the sulphuric acid tube after conducting the ultimate analysis of ·756 grams of alcohol?

401. What volume of air would you expect to find in a vapour density determination of ·860 grams of alcohol (Victor Meyer's method), the temperature of the bath 16° C, pressure 740 mm.? [Tension of water vapour at 16° C 13·536.]

402. Show how to arrive at the molecular formula of a body, the empirical formula being given.

403. A flask which holds exactly 250 cc. of alcohol at 0°C is heated to 50°C. How much of the alcohol will flow out?

404. A glass globe has a capacity of 400 cc. at 0°C. What will be its capacity at 280°C?

405. A block of lead occupies 1000 cubic inches at 0°C. What will be its volume at 100°C?

406. A bar of platinum has a volume of 265 cc. at 0°C. What will be its volume at 1000°C?

407. What change in volume will 728 cc. of mercury undergo in being heated from 0°C to 128°C?

408. Stas found that in heating 91·462 grams of pure silver in dry chlorine he obtained 121·4993 grams of pure argentic chloride. From these data calculate the equivalent of chlorine.

409. Cadmium sulphide contains 77·742 per cent. of metallic cadmium. What is the equivalent of the metal?

410. What weight of Chili salt-petre ($NaNO_3$), will be required to produce 1,297 litres of nitric acid of density, 1·426 containing 66·2 per cent. of its weight of HNO_3?

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APPENDICES.

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I.—Table of the Elements with their Atomic Weights, Symbols, and Atomicities.

[Note.—*The Non-Metals are Printed in Capitals.*]

Symbol.	Name of Element.	Atomicity.	Accurate Atomic Weight.	Approximate Atomic Weight.
Al	Aluminium	IV.	27·3	27
Sb	Antimony	III. V.	120·0	120
As	ARSENIC	III. V.	74·9	75
Ba	Barium.....	II.	136·8	137
Be	Beryllium	II.	9·2	9
Bi	Bismuth	III. V.	208·0	208
B	BORON	III.	11·0	11
Br	BROMINE.....	I.	79·75	80
Cd	Cadmium.....	II.	111·9	112
Cs	Cæsium.....	I.	132·5	133
Ca	Calcium	II.	39·9	40
C	CARBON	IV.	11·97	12
Ce	Cerium.....	IV.	139·9	140
Cl	CHLORINE ...	I.	35·37	35·5
Cr	Chromium	VI.	52·1	52·5
Co	Cobalt	II. IV.	58·6	59
Cu	Copper	II.	63·1	63
Di	Didymium	III.	142·0	—
Er	Erbium.....	III.	166·0	—
F	FLUORINE ...	I.	19·1	19
Ga	Gallium	IV.	69·8	70
Au	Gold	I. III.	196·2	196·5
H	HYDROGEN...	I.	1·0	1
In	Indium.....	III.	113·4	113·5
I	IODINE	I.	126·53	126·5
Ir	Iridium.....	IV.	192·7	193
Fe	Iron	II. IV. VI.	55·9	56
La	Lanthanum.....	IV.	138·0	—
Pb	Lead	II.	206·4	206·5
Li	Lithium	I.	7·01	7
Mg	Magnesium	II.	24·3	24
Mn	Manganese	II. IV. VI.	54·8	55
Hg	Mercury	II.	198·8	200

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I.—Table of the Elements with their Atomic Weights, Symbols, and Atomicities.—*Continued.*

[Note.—*The Non-Metals are Printed in Capitals.*]

Symbol	Name of Element	Atomicity	Accurate Atomic Weight	Approximate Atomic Weight
Mo	Molybdenum.....	VI.	95·8	96
Ni	Nickel.....	II. IV.	58·6	59
Nb	Niobium.....	V.	94·0	94
N	NITROGEN.....	III. V.	14·01	14
Os	Osmium	VI.	198·6	199
O	OXYGEN	II.	15·96	16
Pd	Palladium	II.	106·2	106
P	PHOSPHORUS ..	III. V.	30·96	31
Pt	Platinum	IV.	194·5	194·5
K	Potassium	I.	39·04	39·1
Rh	Rhodium	III.	104·1	104
Rb	Rubidium	I.	85·2	85
Ru	Ruthenium.....	VI.	103·5	103·5
Sc	Scandium		44·	
Se	SELENIUM.....	II. IV. VI.	78·0	78
Ag	Silver	I.	107·66	108
Si	SILICON	IV.	28·0	28
Na	Sodium	I.	22·99	23
Sr	Strontium	II.	87·2	87
S	SULPHUR	II.	31·98	32
Ta	Tantalum	V.	182·0	182
Te	TELLURIUM....	II.	125·0	125
Tr	Terbium.....	II.	148·5	148·5
Tl	Thallium	I.	203·6	204
Th	Thorium.....	IV.	231·5	231·5
Sn	Tin	II. IV.	117·8	118
Ti	Titanium	II. IV.	48·0	48
W	Tugsten	IV. VI.	183·5	184
U	Uranium.....	II. IV. VI.	240·0	240
V	Vanadium	V.	51·2	51·2
Y	Yttrium	III.	89·5	—
Zn	Zinc.....	II.	65·1	65
Zr	Zirconium	IV.	90·0	90

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II.—Table of the Important Simple Compounds of Oxygen with Formulæ, Molecular Weights, and Densities.

Name of Compound.	Formula.	Molecular Weight	Density.
Aluminium oxide	Al_2O_3	102·6	51·3
Antimony anhydride	Sb_2O_5	324	162
Antimony tetroxide	Sb_2O_4	308	154
Arsenic acid	H_3AsO_4	142	71
Arsenic oxide	As_2O_5	230	115
Arsenious acid	H_3AsO_3	126	63
Arsenious oxide	As_2O_3	198	99
Barium hydrate	$Ba(HO)_2$	170·8	85·4
Barium oxide	BaO	152·8	76·4
Boracic acid	$B(HO)_3$	62	31
Boracic anhydride	B_2O_3	70	35
Bromic acid	$HBrO_3$	128·75	64·375
Calcium hydrate	$Ca(HO)_2$	74	37
Calcium oxide	CaO	56	28
Carbonic anhydride	CO_2	44	22
Carbonic oxide	CO	28	14
Chlorous anhydride	Cl_2O_3	119	59·5
Chloric acid	$HClO_3$	84·5	42·25
Chlorine peroxide	ClO_2	67·5	33·75
Hydroxyl (hydrogen peroxide)	H_2O_2	34	17
Hypochlorous acid	$HClO$	52·5	26·25
Iodic acid	HIO_3	275·5	137·75
Magnesia	MgO	40	20

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II.—Table of the Important Simple Compounds of Oxygen with Formulæ, Molecular Weights, and Densities.—*Contd.*

Name of Compound.	Formula.	Molecular Weight	Density.
Mercuric oxide	HgO	216	108
Metaphosphoric acid	HPO_3	80	40
Nitric acid	HNO_3	63	31·5
Nitric anhydride	N_2O_5	108	54
Nitric oxide	NO	30	15
Nitric peroxide	NO_2	46	23
Nitrous anhydride	N_2O_3	76	38
Nitrous oxide	N_2O	44	22
Perchloric acid	$HClO_4$	100·5	50·25
Phosphoric acid	H_3PO_4	98	49
Phosphoric anhydride	P_2O_5	142	71
Potassium hydrate	KHO	56	28
Potassium oxide	K_2O	94	47
Pyrophosphoric acid	$H_4P_2O_7$	178	89
Silicic acid	H_4SiO_4	96	48
Silicic anhydride	SiO_2	60	30
Sodium hydrate	$NaHO$	40	20
Sodium oxide	Na_2O	62	31
Sulphuric acid	H_2SO_4	98	49
Sulphuric anhydride	SO_3	80	40
Sulphurous acid	H_2SO_3	82	41
Sulphurous anhydride	SO_2	64	32
Water	H_2O	18	9

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APPENDIX III.

Mensuration of Areas and Volumes.

1. Plane Areas.

a Area of a *Square* = length of side squared.
b. " *Rectangle*, rhombus, rhomboid = length × breadth.
c " *Triangle* = ½ base × perpendicular.
d. " *Circle* = radius squared × 3·1416.

2. Surfaces.

a Surface of a *Cube* = square of edge × 6.
b. " *Sphere* = diameter squared × 3·1416.
c " *Cylinder* = {2 × 3·1416 × radius (height + radius)}.

3. Volumes.

a. Volume of a *Cube* = edge cubed.
b. Sphere = ⅔ × 3·1416 × radius cubed.
c. Cylinder = area of base × height.
d Cone or Pyramid = ⅓ area of base × height.

APPENDIX IV.

Table of the Specific Gravities of Gases.

Barometer at 20·9 inches.	Air at 0° = 1	Hydrogen at 0° = 1
Air	1·0000	14·4200
Ammonia	·5890	8·5000
Carbonic Acid	1·5246	22·0000
Carburetted Hydrogen :—		
Heavy	·9702	14·0000
Light	·5544	8·0000
Chlorine	2·4602	35·5000
Hydrochloric Acid	1·2540	18·2500
Nitrogen	·9702	14·0000
Oxygen	1·1088	16·0000
Sulphuretted Hydrogen	1·1781	17·0000
Sulphurous Acid	2·2176	32·0000
Hydrogen	·0693	1·0000

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APPENDIX V.

Useful Facts and Constants.

The *Standard Pressure of One Atmosphere* is considered to be that which supports a column of mercury in the barometer of 760 mm., height at 0°C.

This height = 29·922 inches, or very nearly 30 inches.

Mass of a Litre of Dry Air at N T P.	= 1 293 grams.
" *Hydrogen*	1 crith = 0896 "
Percentage of Oxygen in Dry Air by Mass	= 23·18.
" " Volume	= 20 9.
One Gram of Hydrogen at N.T.P. occupies	= 11 16 litres.
Volume occupied by the molecular weight of a gas in grams	= 22 32 "
Mass of a *litre of pure water* at 4°C	= 1000·013 grams.
" *cubic foot of pure water* at 4°C	= 62 425 lbs.
Volume of one pound of pure water at 4°C	= 01602 cubic ft.
Density of aqueous vapour in respect to air	= ·622.
Mean density of the earth	= 5·67.
Coefficient of expansion of the normal gas for 1°6 = $\frac{1}{273}$	= ·003665 nearly.
Latent heat of water	= 79·25.
" steam	= 536.
Specific heat of silver	= 0·056.
" copper	= 0·096.
" iron	= 0·114.
" mercury	= 0·033.
1 cubic foot of fresh water	= 6·26 gals.
1 " "	= 62·5 lbs.
35·6 cubic feet of fresh water	= 1·0 ton.
1 gallon of fresh water	= 10·00 lbs.
1 gallon of sea water	= 10·25 lbs.
1 cubic foot of sea water	= 64·2 lbs.
35 " "	= 1·0 ton.

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APPENDIX VI.

Tension of Water Vapour.

Temperature.	Pressure in Millimetres of Mercury.	Temperature.	Pressure in Millimetres of Mercury.	Temperature.	Pressure in Millimetres of Mercury.
20°C	0·927	12°C	10·457	25°C	23·550
0°C	4·600	13°C	11·165	26°C	24·988
1°C	4·940	14°C	11·908	27°C	26·505
2°C	5·302	15°C	12·699	28°C	28·101
3°C	5·687	16°C	13·536	29°C	29·782
4°C	6·097	17°C	14·421	30°C	31·584
5°C	6·534	18°C	15·357	40°C	54·906
6°C	6·998	19°C	16·346	50°C	91·982
7°C	7·492	20°C	17·391	60°C	148·791
8°C	8·017	21°C	18·495	70°C	233·093
9°C	8·574	22°C	19·659	80°C	354·280
10°C	9·165	23°C	20·888	90°C	525·450
11°C	9·792	24°C	22·184	100°C	760·

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Table of Specific Heats, etc., of Non-Metallic Elements.

	Specific Heat.	Atomic Weight.	Atomic Heat.
Boron, B	·250	11	2·7
Do at 1000°C	·500	11	5·5
Carbon diamond C	·147	12	1·7
Do do at 100°C	·460	12	5·5
Graphite	·198	12	2·4
Silicon, Si	·166	28	4·6
Do above 230°	·203	28	5·6
Phosphorus Crystal, P	·174	31	5·4
Amorphous	·170	31	5·3
Sulphur Rhombic, S	·178	32	5·7
Chlorine, Cl	·093	35·5	3·3
Solid	·180	35·5	6·6
Bromine Liquid, Br	·111	80	8·8
Solid	·084	80	6·7
Iodine, I	·054	127	6·8

Coefficients of Expansion.

Iron	·00003546	Glass	·0000254
Lead	·00008309	Mercury	·0001790
Silver	·00005831	Alcohol	·0010490
Copper	·00004998	Water	·0001815
Platinum	·00002658	Bromine	·0001382

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VII.—THERMOMETER TABLE.

COMPARISON OF CENTIGRADE AND FAHRENHEIT.

C.	F.	C.	F.	C	F.	C.	F.	C.	F.
— 17·7	= 0	7	= 44·6	31	= 87·8	55	= 131	78	= 172·4
— 16	= 3·2	8	= 46·4	32	= 89·6	56	= 132·8	79	= 174·2
— 15	= 5	9	= 48·2	33	= 91·4	57	= 134·6	80	= 176
— 14	= 6·8	10	= 50	34	= 93·2	58	= 136·4	81	= 177·8
— 13	= 8·6	11	= 51·8	35	= 95	59	= 138·2	82	= 179·6
— 12	= 10·4	12	= 53·6	36	= 96·8	60	= 140	83	= 181·4
— 11	= 12·2	13	= 55·4	37	= 98·6	61	= 141·8	84	= 183·2
— 10	= 14	14	= 57·2	38	= 100·4	62	= 143·6	85	= 185
— 9	= 15·8	15	= 59	39	= 102·2	63	= 145·4	86	= 186·8
— 8	= 17·6	16	= 60·8	40	= 104	64	= 147·2	87	= 188·6
— 7	= 19·4	17	= 62·6	41	= 105·8	65	= 149	88	= 190·4
— 6	= 21·2	18	= 64·4	42	= 107·6	66	= 150·8	89	= 192·2
— 5	= 23	19	= 66·2	43	= 109·4	67	= 152·6	90	= 194
— 4	= 24·8	20	= 68	44	= 111·2	68	= 154·4	91	= 195·8
— 3	= 26·6	21	= 69·8	45	= 113	69	= 156·2	92	= 197·6
— 2	= 28·4	22	= 71·6	46	= 114·8	70	= 158	93	= 199·4
— 1	= 30·2	23	= 73·4	47	= 116·6	71	= 159·8	94	= 201·2
0	= 32	24	= 75·2	48	= 118·4	72	= 161·6	95	= 203
1	= 33·8	25	= 77	49	= 120·2	73	= 163·4	96	= 204·8
2	= 35·6	26	= 78·8	50	= 122	74	= 165·2	97	= 206·6
3	= 37·4	27	= 80·6	51	= 123·8	75	= 167	98	= 208·4
4	= 39·2	28	= 82·4	52	= 1 5·6	76	= 168·8	99	= 210·2
5	= 41	29	= 84·2	53	= 127·4	77	= 170·6	100	= 212
6	= 42·8	30	= 86	54	= 129·2				

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APPENDIX VIII.

Metric System of Weights and Measures.

1. Measures of Length.

10 millimetres (mm.)	=	1 centimetre (cm.)
10 centimetres (cm.)	=	1 decimetre (dcm.)
10 decimetres (dcm.)	=	1 metre (m.)
10 metres (m.)	=	1 decametre (dcam.)
10 decametres (dcam.)	=	1 hectometre (hecm.)
10 hectometre (hecm.)	=	1 kilometre (kilm.)
1 metre	=	3·281 feet } nearly.
	=	39·371 inches }

2. Measures of Area or Surface.

100	square milimetres (sq. mm.)	=	1	square centimetre (sq. cm.)
100	" centimetres (sq. cm.)	=	1	" decimetre (sq. dcm.)
100	" decimetres (sq. dcm.)	=	1	" metre (sq. m.)
100	" metres (sq. m.)	=	1	" decametres (sq. dcm.)
100	" decametres (sq. dcm.)	=	1	" hectometre (sq. hcm.)
100	" hectometre (sq. hcm.)	=	1	" kilometre (sq. kilm.)

3. Measures of Volume and Capacity.

10 millimlitres, or cubic centimetres (c.c.)	=	1 centilitre (cl.)
10 centilitres (cl.)	=	1 decilitre (dcl.)
10 decilitres (dcl.)	=	1 litre (l.)
10 litres, or cubic decimetre	=	1 decalitre (dcal.)
10 decalitres (dcal)	=	1 hectolitre (1 hecl.)
10 hectolitres (1 hecl.)	=	1 kilolitre (1 kilol.)

4. Measures of Mass.

10 milligrams (mgrm.)	=	1 centigramme (cgrm.
10 centigrams (cgrm)	=	1 decigramme.
10 decigrams	=	1 gram (grm.)
10 grams (grm.)	=	1 decagram.
10 decagrams	=	1 hectogram.
10 hectograms	=	1 kilogram.
1 gram	=	15·43 grains } nearly.
1 kilogramme	=	2·2 lbs., avoir. }

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APPENDIX IX.

Comparison of Weights and Measures.

1. Weights and Measures.

480·0	grains Troy	=	1 oz. Troy.
437·5	"	=	1 oz. Avoirdupois.
5760·0	"	=	1 lb. Troy.
7000·0	"	=	1 lb. Avoirdupois.

2. Measures of Length.

Millimetre	=	0·03937 inch.
Centimetre	=	0·39371 "
Decemetre	=	3·93708 "
Metre	=	39·37079 "

Inch = 2·5399 centimetres.
Foot = 3·0479 decimetres.

3. Measures of Surface.

Square inch = 6·4513 square centimetres.
Square foot = 9·2899 square decimetres.

4. Measures of Capacity.

Cubic centimetre = 0·0610 cubic inch.
" " = ·00176 pint.
Litre, or cubic decimetre = 61·0270 cubic inch. or 1·760 pint.

Cubic inch = 16·3861 cubic centimetres.
Gallon = 4·5434 litres.

5. Measures of Weight.

Milligram	=	0·0154 grains.
Centigram	=	0·1543 "
Decigram	=	1·5432 "
Gram	=	15·4323 "
Kilogram	=	15432·3488 "

Grain = 0·0647 grams.
Troy oz. = 31·1034 "

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APPENDIX X.

Conversion of Grams or Cubic Centimeters into Ounces and Grains.

1. Conversion of Grams into Grains.

1	gram	=	15·43 grains.
2	grams	=	30·86 ,,
3	,,	=	46·29 ,,
4	,,	=	61·73 ,,
5	,,	=	77·16 ,,
6	,,	=	92·59 ,,
7	,,	=	108·03 ,,
8	,,	=	123·46 ,,
9	,,	=	138·89 ,,

2. Conversion of Grains into Grams.

1	grain	=	·0648 grams.
2	grains	=	·1296 ,,
3	,,	=	·1914 ,,
4	,,	=	·2592 ,,
5	,,	=	·3240 ,,
6	,,	=	·3888 ,,
7	,,	=	·4536 ,,
8	,,	=	·5184 ,,
9	,,	=	·5832 ,,

3. Conversion of Grams into Troy Ounces.

1	gram	=	·03215 Troy ounces.
2	grams	=	·06430 ,,
3	,,	=	·09645 ,,
4	,,	=	·12860 ,,
5	,,	=	·16075 ,,
6	,,	=	·19290 ,,
7	,,	=	·22505 ,,
8	,,	=	·25720 ,,
9	,,	=	·28935 ,,

4. Conversion of Grams into Avoirdupois Ounces.

1	gram	=	·03527 Avoirdupois ounces.
2	grams	=	·07054 ,, ,,
3	,,	=	·10581 ,, ,,
4	,,	=	·14108 ,, ,,
5	,,	=	·17635 ,, ,,
6	,,	=	·21162 ,, ,,
7	,,	=	·24689 ,, ,,
8	,,	=	·28216 ,, ,,
9	,,	=	·31743 ,,

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APPENDIX XI.

COMPARISON OF THE METRICAL WITH THE COMMON MEASURES. BY DR. WARREN DE LA RUE.

(AFTER ROSCOE.)

MEASURES OF LENGTH.

	In English Inches.	In English Feet = 12 Inches.	In English Yards = 3 Feet.	In English Fathoms = 6 Feet.	In English Miles = 1,760 Yards.
Millimeter	0·03937	0·0032809	0·0010936	0·0005468	0·0000006
Centimeter	0·39371	0·0328090	0·0109363	0·0054682	0·0000062
Decimeter	3·93708	0·3280899	0·1093633	0·0546816	0·0000621
Meter	39·37079	3·2808992	1·0936331	0·5468165	0·0006214
Decameter	393·70790	32·8089920	10·9363310	5·4681655	0·0062138
Hectometer	3937·07900	328·0899200	109·3633100	54·6816550	0·0621382
Kilometer	39370·79000	3280·8992000	1093·6331000	546·8165500	0·6213824
Myriometer	393707·90000	32808·9920000	10936·3310000	5468·1655000	6·2163244

1 Inch = 2·539954 Centimeters
1 Foot = 3·0479449 Decimeters.
1 Yard = 0·91438348 Meter.
1 Mile = 1·6093149 Kilometers.

MEASURES OF SURFACE.

	In English Square Feet.	In English Sq. Yards = 9 Square Feet.	In English Poles = 272·25 Sq. Feet.	In English Roods = 10,890 Sq. Feet.	In English Acres = 43,560 Sq. feet.
Centiare or square meter	10·7642993	1·1960333	·0395383	0·000988457	0·0002471143
Are or 100 square meters	1076·4299342	119·6033260	3·9538290	0·098845724	0·0247114310
Hectare or 10,000 square meters	107642·9934183	11960·3326020	395·3828959	9·884572398	2·4711430996

1 Square Inch = 6·4513669 Square Centimeters.
1 Square Foot = 9·2899683 Square Decimeters.
1 Square Yard = 0·83609715 Square Meter or Centiare.
1 Acre = 0·404671021 Hectare.

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MEASURES OF CAPACITY.

	In Cubic Inches.	In Cubic Feet = 1,728 Cubic Inches.	In Pints = 34·65923 Cubic Inches.	In Gallons = 8 Pints = 277·27384 Cubic Inches.	In Bushels = 8 Gallons = 2218·19075 Cubic Inches.
Milliliter or cubic centimeter	0·061027	0·0000353	0·001761	0·00022010	0·000027512
Centiliter or 10 cubic centimeters.	0·610271	0·0003532	0·017608	0·00220097	0·000275121
Deciliter or 100 cubic centimeters.	6·102705	0·0035317	0·176077	0·02200967	0·002751208
Liter or cubic decimeter	61·027052	0·0353166	1·760773	0·22009668	0·027512085
Decaliter or centistere	610·270515	0·3531658	17·607734	2·20096677	0·275120846
Hectoliter or decistere	6102·705152	3·5316581	176·077341	22·00966767	2·751208459
Kiloliter or stere, or cubic meter.	61027·051519	35·3165807	1760·773414	220·09667675	27·512084594
Myrioliter or decastere	610270·515194	353·165·074	17607·734140	2200·96676750	275·120845937

1 Cubic Inch = 16·3861759 Cubic Centimeters. 1 Cubic Foot = 28·3153119 Cubic Decimeters.
1 Gallon = 4·543457969 Liters.

MEASURES OF WEIGHT.

	In English Grains.	In Troy Ounces = 480 Grains.	In Avoirdupois Lbs. = 7,000 Grains.	In Cwts. = 112 Lbs. = 784,000 Grains.	Tons. = 20 Cwt. = 15,620,000. Grains.
Milligram	0·015432	0·000032	0·0000022	0·00000002	0·000000001
Centigram	0·154323	0·000322	0·0000220	0·00000020	0·000000010
Decigram	1·543235	0·003215	0·0002205	0·00000197	0 000000098
Gram	15·432349	0·032151	0·0022046	0·00001968	0·000000984
Decagram	154·323488	0·321507	0·0220462	0·00019684	0·000009842
Hectogram	1543·234880	3·215073	0·2204621	0·00196841	0·000098421
Kilogram	15432·348800	32·150727	2·2046213	0·01968412	0·000984206
Myriogram	154323·488000	321·507267	22·0462126	0·19684118	0·009842059

1 Grain = 0·06479895 Gram. | 1 Lb. Avd. = 0·45359265 Kilogr.
1 Troy oz. = 31·103496 Gram. | 1 Cwt. = 50·80237689 Kilogr.

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CHEMICAL PROBLEMS

AND

KEY,

FOR USE OF

TEACHERS AND STUDENTS.

ADAPTED FOR THE USE OF STUDENTS PREPARING FOR THE UNIVERSITIES,
SOUTH KENSINGTON, SOCIETY OF ARTS, CIVIL SERVICE,
AND MEDICAL SCHOOLS EXAMINATIONS.

By

JOHN J. PILLEY.

GEO. GILL & SONS, 13, WARWICK LANE, LONDON, E.C.

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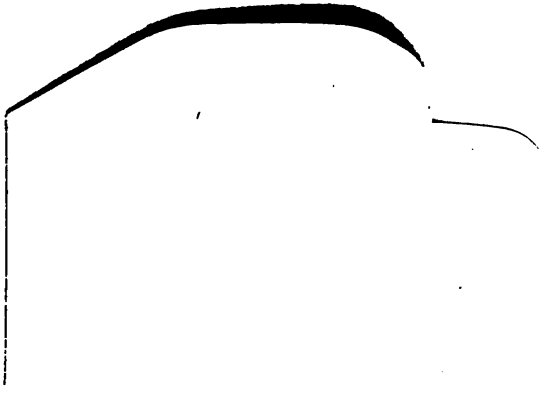

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